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Sludge Management Planning in the Boston Metropolitan Area - A Case Study

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Management planning
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ABOUT THIS REPORT

The attached is one of a group of four contractor-prepared reports which collectively comprise Phase II of a government-sponsored study, "Scientific and Technical Evaluation of the Environmental Protection Agency's Wastewater Treatment Facilities Grants Planning Process - Boston Case Study." The study examines current administration of the municipal wastewater treatment facilities construction grants program established by the Federal Water Pollution Control Act Amendments of 1972 and modified by the Clean Water Act of 1977.

The reports were prepared for a federal interagency study team composed of representatives of the National Science Foundation, the President's Council on Environmental Quality, the Office of Management and Budget, and the Environmental Protection Agency headquarters. Draft copies of these reports were made available to the public in August 1978 and were the subject of agency and public meetings in September 1978. Written comments were solicited from governmental agencies, public interest groups, and the general public. They are noted and responded to by the contractors in the final printed reports.

The objective of the study was to examine recent operation of the Construction Grants Program, using the Boston Metropolitan Area as a case study, with a view toward developing recommendations for possible legislative or administrative actions at the national level to (1) improve the administration of the program in general; (2) upgrade the scientific and technical basis for decisionmaking; and (3) assure that federal funds are used in a cost effective way to achieve national water pollution cleanup goals.

The four reports comprising Phase II of this study are

Kennedy Engineers, Inc., Wastewater Treatment Facilities Planning in the Boston Metropolitan Area - A Case Study. Engineering Report. January 1979.

Environmental Research & Technology, Inc., Water Quality Goals, Objectives, and Alternatives in the Boston Metropolitan Area - A Case Study. February 1979.

Environmental Research & Technology, Inc., Sludge Management Planning in the Boston Metropolitan Area - A Case Study. January 1979.

Urban Systems Research & Engineering, Inc., Institutional Aspects of Wastewater Management: The Boston Case Study. January 1979.

Our signatures indicate that this study was conducted under our supervision, but they do not imply our agreement, individually or collectively, with the study findings, conclusions, or recommendations.

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National Science Foundation

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Council on Environmental Quality

Sludge management planning in the Boston metropolitan area-- a case study

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PREFACE

This evaluation of sludge management planning in the Boston Metropolitan Area was sponsored by the National Science Foundation and undertaken as part of a comprehensive Boston Case Study of the Clean Water Grant Program administered by the U.S. Environmental Protection Agency (EPA) under the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and the Clean Water Act of 1977, PL 95-217. Representatives from four federal agencies composed an interagency team:

- the National Science Foundation (NSF),
- the Office of Management and Budget (OMB),
- the Council on Environmental Quality (CEQ) and
- the EPA.

Contractors involved in the detailed studies were:

- Kennedy Engineers, Inc., San Francisco, CA; contractor to NSF for Facilities Engineering;
- Urban Systems Research & Engineering, Inc., Cambridge, MA; contractor to CEQ for Financial and Institutional Analyses;
- Environmental Research & Technology, Inc., Concord, MA; contractor to NSF for Sludge Management Policies Analysis and
- Environmental Research & Technology, Inc. Concord, MA; contractor to CEQ for Water Quality Goals and Objectives.

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This study was conducted with the participation of numerous individuals in addition to those directly part of the project team. Other people at ERT provided inputs. Ben Greene and Beth Taylor provided air quality inputs and Barbara Goldsmith provided ocean dumping policy inputs. Several individuals at the Metropolitan District Commission (MDC) deserve acknowledgment. In particular Andrew Fisichelli, Former Assistant Director of the MDC's Sewerage Division, provided insight into the MDC's sludge treatment and disposal practice as well as its pretreatment policy. Martin Weiss, Chief Engineer, and Libby Blank, Director of Environmental Planning, also provided the study team with useful background information. Noel Baretta is thanked for his help in describing the MDC's industrial waste management program, and Tony Guarciariello is thanked for providing data on heavy metals content of Deer Island sludges.

Acknowledgement is also made to Mary Shaughnessey, Wallace Stickney and Ira Leighton of Region I EPA. Important background information on EPA's involvement in sludge management planning at the federal level was provided by Robert Bastian and Eileen Claussen.

Others deserving mention include the Public Works Departments of Boston and Malden, Camp, Dresser and McKee, Inc., Clean Communities Incorporated, Army Corp of Engineers and the MAPC Citizen Advisory Committee.

The study team particularly appreciated the generous help of Envirotech Corp. for their computer analysis of fuel consumption and would like to thank Dr. Joel Jacknow for his critical review of the draft document.

Many helpful suggestions were made by William Anderson of Kennedy Engineers and J. Douglas Smith. Special appreciation is extended to Carroll Bastian (formerly of National Science Foundation) for her encouragement and guidance on the project. Similarly, Richard Morrison, project officer, National Science Foundation, deserves special thanks for his patience and wisdom in seeing that this project accomplished its objectives. Finally, the project team thanks Anne Jones, ERT's technical editor for her careful attention to this study.

ABSTRACT

This report presents a review and analysis of planning efforts for disposal of wastewater sludges in the Boston metropolitan area. Early planning studies conducted by the Regional Environmental Protection Agency (EPA) and the Metropolitan District Commission (MDC) are critically reviewed, and the key technical, economic and institutional factors influencing the planning process are identified. The cost of 9 basic sludge treatment and disposal options, consisting of 28 process variations, are analyzed, and a sensitivity analysis is performed to reveal how future technical, economic and regulatory changes may affect present decisions. For example, changes in the price of fuel and its resulting affect on each disposal option cost are analyzed.

Principally, this study finds that the operational performance of the recommended incineration option is highly uncertain. This conclusion is based on data obtained from a survey of advanced-design incinerators in which difficulties were observed in obtaining high solids content sludge cake. Another option, composting, was found to be technically acceptable, cost effective and potentially easily implemented if a site were available on Deer Island. MDC sludge quality was found to be suitable for land application purposes; however, it appears that the MDC would be unable to implement this option because land outside the sewerage district is difficult to obtain.

This report also considers the benefits of delaying committment to a sludge management system, particularly during a period of rapid technical and regulatory change. A decision tree was designed to determine the advisability of building the proposed incinerator now or waiting five years. The analysis indicates that if the probability that ocean discharge would be acceptable is over 10%, both the MDC and the nation would benefit economically if committment to other options is delayed and temporary alternatives are chosen. Recommendations that the scientific bases of the ban on ocean disposal of sludge should be re-examined were made to Congress and the U.S. EPA. In addition, recommendations that the EPA play a more effective role in distributing information to municapilities on newly introduced technologies such as advanced forms of incineration were also made to avoid extensive construction programs that are subsequently found to not meet performance specifications.

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EXECUTIVE SUMMARY

PREFACE

This study, sponsored by the National Science Foundation (NSF), evaluates sludge management planning in the Boston Metropolitan Area as part of a comprehensive "Boston Case Study" evaluating the effectiveness of the Clean Water Grant program. This program is administered by the Environmental Protection Agency (EPA) under the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and the Clean Water Act of 1977 (PL 95-217). Several other federal agencies are participating as members of an interagency team: the Office of Management and Budget (OMB), the Council on Environmental Quality (CEQ) and the EPA.

Although this report uses Boston as a case study to evaluate sludge management planning, information relating to both federal regulations and technologies is directly applicable to the experiences of other municipalities. Furthermore, the experience gained from dealing with local problems that at first appear unique is often useful to many other municipalities.

The purpose of this study is to evaluate the sludge management planning program in the Boston Metropolitan Area, in order to suggest recommendations for:

- improving the administration of water pollution programs, including sludge management and planning;
- upgrading the scientific and technical basis for decision making;
- increasing the confidence level in the cost-effectiveness estimates and environmental soundness of federal sludge management plans; and
- providing an analysis and understanding of the Boston experience that will improve sludge management planning in Boston and other metropolitan regions.

This study contains five sections with appendices. Section 1 identifies the problems associated with sludge management planning, describes the service area and a study area chronology and finally describes the study approach.

Section 2 analyzes the critical technological issues affecting sludge management planning, evaluates major sludge treatment and disposal methods and identifies key process and institutional variables. Section 3 uses the technical findings presented in Section 2 to formulate a set of primary sludge management options. Primary sludge management options are emphasized because documented federal involvement in sludge management planning in the Boston area has been limited thus far to projected Phase I 1985 primary sludge planning*. Detailed cost and environmental analyses are performed for nine basic disposal alternatives under existing technical and federal policy constraints.

Section 4 considers the effect of removing certain constraints from these options, such as removing the federal ban on ocean dumping of sludge. It then presents a set of costs, technologies and standards for each of these proposed options. In addition, this section recommends a procedure allowing planners to make decisions under conditions of uncertainty. Section 5 discusses how policies at different levels of governmental influence sludge management planning on the local level and finally recommends improvements to sludge management planning on both the local and national level.

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*The bulk of the technical data and analysis presented in this report was based on information acquired up to January 1978. Responses to comments generated during the public review period in some reflect a time period up to September 30, 1978.

1. INTRODUCTION

Overview

Approximately 7 million tons per year of municipal wastewater sludges are projected to be produced nationally by the year 1980. This situation has occurred as a result of EPA-administered programs, which have been underway since 1972, for upgrading old and building new municipal sewage treatment facilities. Since sludge is a product of wastewater treatment, the more thorough this treatment is, the more sludge will be produced per unit volume of treated wastewater*. The planning required for the disposal of such quantities of material is a complex task that is receiving considerable emphasis on national and local levels. Another reason for the current emphasis on sludge management planning is that until recent times sludge management planning was largely ignored and uncoupled from other aspects of the wastewater treatment facilities planning**.

The composition of sludge depends on the materials suspended or dissolved in the "raw" wastewater and the type and efficiency of the wastewater treatment process. Primary treatment facilities remove solids by physical separation techniques such as screening and sedimentation and produce sludges containing large amounts of inorganic substances such as sand and clays and low concentrations of nutrients (phosphorus and nitrogen). Biological secondary treatment facilities employ bacteria to treat wastewater, and the resulting sludges contain higher concentrations of biological solids and nutrients. In its unstabilized or "raw" form, sludge is putrescrible and a hazard to public health. In its highly stabilized form (such as aged compost) sludge is relatively innocuous, having an earthy consistency and beneficial soil amendment properties.

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*Sludge is the residue material from wastewater by a treatment process and may exist as a dilute suspension in water (e.g., 1% solids), as a concentrated suspension (e.g., 15% solids) or a drier more concentrated cake.

**In one relatively recent preliminary engineering plan for a 65 million gallons per day (mgd) advanced wastewater facility (which included nitrogen and phosphorus removal) at most two pages of discussion out of a total of 200 were dedicated to handling and disposing nearly 100 dry tons per day of sludge generated. Piscataway Regional Wastewater Management Study for Washington Suburban Sanitary Commission, Bechtel Inc., February 1975.

Sludge can be treated and disposed of in a manner allowing recovery of its valuable constituents, which consist of chemicals with fertilizing and soil conditioning properties and the potential energy of its organic matter. Landspreading and composting, as well as advanced types of incineration, are practices that both render sludge innocuous and recover a portion of its nutrient or energy value. Other types of treatment and disposal, such as conventional types of incineration/landfilling and ocean disposal, at best render the material innocuous.

All methods of sludge disposal involve certain environmental impacts and economic costs that must be evaluated by sludge management planners. At a minimum, a sludge management plan has three engineering and environmental objectives:

1) to stabilize organic matter and reduce sludge volume;
2) to minimize adverse impacts to air, water and soil environment and
3) to dispose of sludge at the lowest total annual cost.

Although these three objectives form an important basis of sludge management planning, they are in themselves incomplete because of the numerous legal, technical and local factors now requiring consideration before an environmentally acceptable and cost-effective plan can be developed. For example, a federal law such as the Ocean Dumping Act can exert a major influence on the sludge planner as a result of the very stringent standards that may effectively eliminate an option (such as ocean dumping). The absence of regulations such as published federal standards of performance for the landspreading and landfilling methods of sludge disposal (called for as part of the Resource Conservation and Recovery Act, but not promulgated as of January 1, 1979) can also cause difficulties for the planner.

The methods for sludge treatment and disposal also contribute to a planner's difficulties because of their performance uncertainties and increasing costs. For example, conventional forms of incineration consume large quantities of fuel oil and face economic uncertainty as a result of increasing fuel costs. Newer types of incinerators are being designed to operate without auxiliary fuel; however, little operating information is available, and the planner has only theoretical design information with which to base a technical choice. Spreading sludge on agricultural soil for purposes of using its nutrients in crop production has been a popular disposal method, particularly in agricultural regions. As a result, landspreading methods are reliable and proven; however, planning uncertainties are evident. In particular, site availability and the absence of metal contaminants such as cadmium contribute to planning difficulties.

Composting, a sludge stabilization and dewatering process, has received intensive investigation in recent years and is being instituted on a large scale by a 300-mgd Blue Plains wastewater facility in Washington, D.C., but this technique is also uncertain. For example, the composting process has not been completely evaluated under a wide range of environmental conditions, nor have the public risks associated with both the treatment process and the end product use been fully explored.

Historically, landfill is the most widely employed disposal method, but this method now has two complications: the availability of nearby sites in most urban areas is rapidly diminishing, while the costs per mile of hauling sludge to remote landfill sites is increasing. Secondly, increased costs are incurred when newly required leachate control and monitoring systems are incorporated in the plans.

The third category of factors that contribute to the complexity of sludge management planning is distinctly local and includes the quantity and quality of sludges, geographical relationship between the point of sludge generation and the point of its disposal, local and state regulations and personal biases of the planner.

From this discussion, two additional objectives can be added to the list of three that compose a sludge management plan. These objectives are to:

4) select disposal methods that will continue to function cost effectively under a range of potential new environmental regulations and

5) maintain the municipality's flexibility for taking advantage of technological changes.

Boston Case Study

Sludge management planning is being conducted in the Boston Metropolitan Sewerage District (MSD), which includes 43 communities covering 500 square miles and provides sewerage service to about two million people. The MSD is currently served by two primary sewage treatment plants, one at Deer Island (average daily flow of 343 mgd) and one at Nut Island (average daily design flow of 112 mgd and over loaded at 123 mgd in fiscal year 1975-1976). The MSD is operated by the Metropolitan District Commission (MDC).

The two treatment plants presently discharge liquid, anaerobically digested sludge through outfalls into Boston Harbor at ebb tide. Most of the material is presumably carried out to sea, but some small quantity may be deposited and recirculated within the Harbor. This condition is deemed unacceptable by the EPA and the development of alternative plans for the disposal of sludge has been undertaken by the MDC for review and approval by EPA Region I.

2. EVALUATION OF TECHNOLOGY OPTIONS FOR SLUDGE DISPOSAL

The MDC, charged with developing sludge disposal plans, engaged the consulting engineers, Havens and Emerson, Ltd (H&E) whose 1973 report is examined in detail along with the Draft Environmental Impact Statement (EIS) prepared for EPA Region I by EcolSciences (1976). This EIS* is the major EPA document covering the primary sludge planning process and was prepared in accordance with the administration of PL 91-190, the National Environmental Policy Act (NEPA). NEPA requires the EPA to prepare an EIS accounting for major actions, such as decisions to fund the primary sludge plan (Phase I), and issue a National Pollutant Discharge Elimination System (NPDES) Permit pursuant to the secondary sewage treatment plan, as well as to provide funding (Phase II). In addition, the EPA Region I carries out a number of other programs that have important implications for MDC sludge planning, including (1) approvals for funding under PL 95-217 Section 201, the Construction Grants Program and (2) discharge permits issued pursuant to the NPDES.

The two documents mentioned above provided a considerable amount of planning and engineering data for review and evaluation. The MDC plan by H&E addressed primary sludge from the existing Deer and Nut Island facilities, as well as sludge from secondary treatment facilities projected through 1995. The EPA, however, evaluated (through 1985) only the primary sludge portion of the plan in the Draft EIS because they deemed it practical to cover secondary sludge separately as part of the EIS being prepared for expansion of sewage treatment to include secondary treatment facilities. (This EIS has not been released.)

According to officials, the EPA believes this manner of evaluation should provide a more coherent EIS review of the secondary sewage treatment proposal, but allowed a decision on primary sludge management to move forward independently. The primary sludge plan was viewed as a remedial measure aimed at correcting an immediately unacceptable condition in Boston Harbor, and EPA did not wish to delay action by linking a decision to a resolution of future problems posed by secondary sludge.

In the EIS, however, the EPA did more than merely evaluate the alternatives presented when reviewing the MDC plan:

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*The EIS has remained in draft form through December 1978.

> The purpose of the EIS is to evaluate not only the system proposed by the MDC, but also to expand the scope of the investigation of feasible alternatives. Since the proposed plan is of a controversial nature, we felt that an independent evaluation and reexamination of feasible sludge disposal alternatives should be performed by EPA itself. Consequently, we expanded the scope of alternatives beyond those originally submitted by the MDC by performing our own in-depth analysis of the feasible disposal alternatives (EcolSciences 1976).

In fact, by creating a new set of alternatives, the EPA performed a preliminary engineering evaluation (normally performed in Section 201 of the facilities planning process) within the context of an EIS.

The combined considerations of the MDC and the EPA have generated a large number of alternatives, and an MDC recommendation to incinerate was finally confirmed by the EPA in the Draft EIS. This decision took into account a "side study" by Stone and Webster in which coincineration with Boston municipal solid wastes was considered and then rejected.

This section reviews the manner in which each of the numerous alternatives for primary sludge management were evaluated. This review requires a degree of engineering detail, as well as maintenance of the planner's perspective, and develops additional considerations by:

1) showing how the range of alternatives can be expanded, particularly if certain policy constraints are relaxed, and
2) showing how some of the alternatives could be analyzed in more depth, producing results that would influence the decision.

Resources simply did not permit equal treatment of all alternatives. Because of the generosity of an equipment manufacturer who allowed the use of a proprietary computer program, the combustion alternatives were developed in greater depth than had been anticipated when work was started. Nevertheless, the combustion alternatives merit emphasis since incineration was the final MDC and EPA decision*, and this review shows that the planning documents do not display all relevant decision factors.

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*At the time of this writing the two agencies differed only in alternative methods of ash disposal.

Land and ocean disposal alternatives are somewhat more controversial than combustion alternatives, and the environmental and scientific issues are complex; however, these issues and alternatives are not as technically difficult to describe and review as are the combustion alternatives, which are generally capital intensive, can cause problems in air quality compliance and can reduce the planner's confidence about projected operating costs because of technological uncertainties. Ocean disposal requires the simplest technology and is the least expensive option, but its adoption (however rational) would be contrary to current federal policy. Land disposal can cost as much or more than incineration per dry ton disposed. The use of sludge in agriculture, while consistent with both state and federal policy in principle, is highly controversial within the EPA and other agencies because of both the perceived risks associated with the presence of heavy metals and other contaminants in the sludge, as well as the local institutional factors that make implementation difficult. These and other issues are developed in the detailed review of alternatives.

The review begins by framing some of the given conditions and circumstances around which all technology options must be developed. Thus, Section 2.2, Sludge Management Issues, includes:

- projected sludge quantities,
- projected sludge composition and
- transportation considerations.

The detailed technology review of the options is organized as follows:

- Combustion Alternatives
  - incineration
  - pyrolysis
  - co-combustion with municipal solid wastes

- Land Disposal Alternatives
    - sludge utilization (raw, digested or composted)
    - composting
    - land reclamation
    - land filling
- Ocean Disposal Alternatives
    - ocean discharge
    - ocean dumping

The balance of this Executive Summary provides a brief overview of the technical findings and a discussion of policy implications.

Sludge Management Issues

Projected Sludge Quantities

Several different projections of sludge quantity by the MDC and others are displayed, since various planners used different projections. To develop a single baseline for later comparison of alternative projects, this section develops a standard set of primary sludge projections, based primarily on the Draft EIS.

The generation rate of raw sludge solids is 269,000 dry lb/day based on MDC's fiscal 1975-76 report. By 1985, this total is projected to be 439,000 lb/day. By 1995, with the secondary treatment facilities in place, total sludge generation will approach 819,000 lb/day. Digestion is projected to reduce these quantities to 239,000 lb/day in 1985, but no digestors are expected to be in operation by 1995.

Projected Sludge Composition

Data are available for heavy metals and nitrogen, but are limited for pesticides and refractory organics. Nitrogen is the major nutrient in sludge. Operating data suggest that Nut Island digestors are more effective in converting organic nitrogen to ammonium than those at Deer Island and that chloride fluctuations periodically inhibit digestor performance at Deer Island.

Heavy metals data were obtained from MDC records, and the mean monthly sludge values were determined for 9 metals over a 4-year period. The data show, among other things, that Deer Island Sludge is significantly higher in metal content than Nut Island sludge for copper, chromium cadmium and zinc. The cadmium content of Deer Island sludge was found to be moderately high when compared to sludges from other municipalities. Thus, spreading sludge for agricultural uses and at the same time complying with EPA's proposed criteria could be a problem. Metals are apparently derived from a combination of industrial sources and from street runoff. Preliminary data suggest that industrial sources are primarily responsible for metals in Deer Island sludge.

Transportation Considerations

First, local studies are reviewed for transportation consideration, then a set of transportation modes to be used in developing costs is described in relation to each sludge disposal option. Finally, the local costs are developed and justified by available data.

Combustion Alternatives

The economics of combustion are reviewed, focusing on the energy surplus or deficit associated with various combustion cases. The conditions for autogeneous combustion (that is, combustion without the need for supplemental fuel) are important to consider. Generally, a solids content of 30% to 35% is the minimum required for autogeneous combustion, while higher solids content will yield expendable energy useful in steam or electric generation.

A major uncertainty in the economic performance of any combustion alternative is the dryness of the sludge cake that is fed into a combustion unit. General experience suggests that primary digested sludge, such as that produced at Deer and Nut Islands, may be dewatered to 25% to 40% in solids content with presently available dewatering equipment. However, the limited experience with dewatering tests of Deer Island digested sludge, in which a filter cake could not be formed, suggests that the performance of dewatering equipment cannot be taken for granted. Thus, any plans for combustion, assuming specific dewatering capabilities must be carefully evaluated and supported by pilot tests.

Incineration

The major operating factors that will determine the economic performance of an incinerator are:

- solids content of the sludge feed,
- heat value of the sludge,
- percentage excess air (excess over and above theoretical requirements) and
- furnace exhaust temperature.

These four factors taken together will determine supplementary fuel requirements and potential for waste heat recovery. Computer heat balances provide comparative results for eight different combinations of these factors.

The results of this review differ from those obtained by H&E or EcolSciences. The 1973 Sludge Plan and the Draft EIS base the economic performance of incinerators on autogeneous combustion at solids contents of 26% and 30%, respectively; however, the study team's calculations indicate that autogeneous combustion is not achieved until the solids content is somewhat greater than 30%.

For the case of sludge at 30% solids when an afterburner is required for air pollution control, the No. 2 fuel oil requirement may be as high as 130 gallons per hour per incinerator, or about 1,890,000 gallons per year when operating two furnaces at the average daily sludge rate (a "worst case," but clearly plausible outcome). Intermediate cases also show significant fuel requirements. For example, without afterburners, but at 26% solids, the fuel requirement would average 855,000 gallons per year for two furnaces. The documented decision to use an incinerator does not explicitly account for the economic and energy consequences of process uncertainties and is thus considered a serious problem.

To add perspective, the incinerators at 1985 conditions would consume about 46,000 tons per year of sludge (dry weight). At one million gallons of fuel per year, about 21 gallons of fuel per ton of sludge is indicated. At the current price of $0.50/gallon, the cost would be $10.50 per ton of sludge for fuel alone.

These and other uncertainties related to incineration are developed. Incinerator operating experience, which adds to concern for the reliability of this option, is cited. The planner/decision maker must ensure that, despite the uncertainties, the decision is the best one available and must take concrete steps to minimize uncertainties. A critical review of the documented studies fails to reveal that these procedures were adequately followed.

Pyrolysis

Pyrolysis is the reduction of organic matter under controlled temperature conditions in an oxygen-deficient atmosphere. Gaseous products containing fuel value result and are burned in an afterburner along with supplemental fuel, if necessary, to provide heat for the process. Pyrolysis offers the advantages of improved temperature control, reduced clinker formation and reduced particulate matter emissions.

Pyrolysis of sewage sludge is a less developed technology than incineration, and there is very little sludge pyrolysis operating experience. However, since it is an emerging technology that has been recommended in other urban areas, examining its potential for Boston is useful. The 1973 H&E study did not consider pyrolysis because, at that time, it was considered a high risk technology. The 1976 Draft EIS eliminated it after a brief technical evaluation.

An energy evaluation for three potential digested sludge cases and one raw sludge case is presented. Using raw sludge at 40% solids, the process may be autogeneous. However, at 40% solids using digested sludge, 309,000 gallons per year of No. 2 fuel oil is required at 1985 conditions. If all other conditions are constant, 30% sludge solids would require 1,962,000 gallons per year. Clearly, pryolysis is best applied to undigested sludge. When afterburners are required, the performance advantages of pyrolysis, when proven, may recommend it over incineration.

Because of the inherent use of afterburners, the operating costs of pyrolysis are even more sensitive to uncertainty in the percent sludge solids than incineration. Unless 40% or higher solids can be assured, pyrolysis would not appear to be competitive with the proposed incinerators if afterburners are not required.

Coincineration/Copyrolysis

The Stone and Webster study evaluated a coincineration option and found a lower annual cost than the combined total of separate sludge and solid waste incineration. However, since the federal-state capital grant structure would support a sludge incinerator, but only a small portion of a municipal solid waste incinerator that would also accept sludge, there appears to be no practical way for the coincinerator owner (such as the City of Boston) to take advantage of the cost savings. The study concluded that this fact, coupled with the added transportation cost of sludge, should eliminate coincineration from further consideration by the MDC.

Results presented here show that a 1,500 tons per day (tpd) municipal incinerator would have a gross unit cost of $10.11 per ton for operation and maintenance and fixed cost. By adding 427 wet tons of sludge at 30% solids, total gross unit costs increase by 53% to $15.49 per wet ton, including sludge. The comparison cost for copyrolysis is $16.10 per wet ton.

Further analysis shows that all three options have significant value recovery potential from production of steam and separation of ferrous and aluminum materials. All three cases yield between 5.3 and 5.8 million dollars per year, mainly from steam sales, enough to offset the O&M cost and contribute a portion to the capital costs.

This study found coincineration to be a favorable sludge option. As can be seen in Section 3, it results in about $90/dry ton net cost compared with $105 to $120 for sludge incineration only.

The major issues are institutional and relate to the federal funding structure. A privately-owned incinerator simply would not qualify for any federal funds. A publicly-owned incinerator, under current conditions, will probably not receive federal funds for construction since none have been allocated under the Resource Conservation and Recovery Act of 1976. However, a publicly-owned incinerator may be eligible, under the construction grants program of PL 95-217, for grants on a prorated basis to cover the increased construction costs imposed by sludge.

Important economies of scale as well as significant resource recovery can be achieved by coincinerating sludge with municipal solid waste. These economies will not be achieved unless they can be realized by the owner of the incinerator. Federal funding policy on solid wastes and clean water needs to be coordinated if these economies are to be achieved.

Air Quality

This section reviews the impacts on local air quality of incinerator emissions and finds that the air quality modeling performed by EcolSciences in the Draft EIS did not address worst-case conditions for two reasons.

1) EcolSciences used the most frequent meteorological condition as the worst case instead of the conditions giving the highest concentration of pollutants.

2) EcolSciences stated that there would be no problem with aerodynamic effects of the incinerator structure. In fact, the 10-m/sec exit velocity of the design stack sufficiently suppresses stack downwash only for wind speeds less than 15 miles per hour. Wind speeds greater than 15 miles/hour are frequent in the harbor area. EcolSciences' assumption of normal plume rise from the incinerator stack is in error for worst-case conditions. Consequently, their calculated pollutant concentrations are lower than those that will probably occur.

Land Alternatives

The disposal methods listed under this category include methods such as landspreading, composting and landfilling.

Landspreading

Both H&E and EcolSciences evaluated landspreading of sludge with agricultural application and decided against this option, primarily because of its costs. EcolSciences found other significant problems with this option, including site availability and public health concerns associated with metal contamination of crops and soils.

ERT, in a review of national literature, found that the landspreading option was being successfully employed by many small to medium (150,000 population) midwestern cities as well as by a major metropolitan area, Chicago, and that the disposal method was generally both technically reliable and environmentally acceptable.

This section examines the suitability of Deer and Nut Island sludge for application to soil for the growth of an animal feed crop (such as corn). From the standpoint of nutrient, metal, pathogen and salt content, this section concludes that present day sludges could be land applied at agronomic loading rates. Under good agricultural management practices land application would not cause significant short-term environmental impacts. The section then recommends that the salt content of Deer Island liquid sludge be reduced to ensure that long-term groundwater problems do not develop. The content of cadmium, the most controversial metal, was found to require a 50% reduction to maintain an unlimited nitrogen loading rate and still meet EPA's proposed 1985 cadmium loading limitation.

The major public health concern in sludge use programs is the issue of heavy metals. Data on the impact of heavy metals are incomplete, and the EPA has currently developed criteria and is in the process of developing guidelines for "safe" agricultural application of metal-containing sludges. To date, however, the metals issue remains controversial. In the absence of complete criteria and guidelines, a planner is in a very poor position to justify the sludge use alternative without potentially burdening himself with cost constraints. The most significant observation here is that sludge use as a disposal option is being rapidly developed nationally. Although the technical feasibility has been demonstrated throughout the country, advances primarily in federal and state policies, coupled with projected increased costs of synthetic fertilizer, will make this option more cost competitive and feasible for many areas in the future.

Composting

Neither H&E nor EcolSciences considered the composting option as a treatment and disposal option. The technique of composting municipal sewage sludges was reviewed nationally. The study team found that this option has emerged from an option receiving little large-scale engineering study in 1972 to one that is now eligible for EPA's construction grants awards. Because of this technical development, the study team concluded that the composting option should be considered as an option for treatment and disposal of primary sludge as well as secondary sludge.

The study team found the composting option to be cost effective if a composting site were available at Deer Island. Furthermore, it concluded that the MDC would be able to implement this option because of the availability of 15,000 acres of MDC-owned parkland and thousands of additional acres of parkland owned by member communities of the MSD. To stimulate involvement by each member community in the compost disposal option, the MDC could require member communities to receive a quantity of composted sludge proportional to its sewage contribution.

Reclamation

The limited available data do not permit a complete land reclamation evaluation. The H&E study and the Draft EIS did not include this option. Land is mined in Middlesex and Plymouth counties, adjacent to Boston, for sand, gravel and stone. Although over 10,000 acres of disturbed lands were found to exist, neither data on outstripped lands nor a schedule for rehabilitation were available. Land reclamation remains one of the most attractive land-oriented options because of its overall environmental and economic value, and additional studies should pursue this option further.

Landfilling

H&E and EcolSciences both considered and rejected landfill as a sludge disposal alternative. Both studies did consider landfill as a disposal method for incineration ash. Suitable siting of landfills is a major regional issue and, as a result, the need to consider increasingly remote sites results in costs per dry ton similar to the incineration option.

While landfills do not require the advanced technology of the combustion alternatives, their implementation is complex. Proposed new sites are inevitably controversial and protecting groundwater from leaching contaminants requires detailed monitoring.

Ocean Disposal

Two types of ocean disposal options, the most economical options in this study, are considerd. Ocean discharge involves constructing an outfall pipe from the treatment plants to a stationary discharge point in the ocean. The cost will clearly depend on the length of the discharge pipe required. Ocean dumping involves barging dewatered sludge to one or more dump zones.

Ocean discharge and dumping of sludge were both considered in the EcolSciences studies. Ocean disposal was rejected only because the weight of federal policy mitigates against it. While new dumping is apparently prohibited, discharge may be permitted. However, a discharge permit is difficult to obtain, as described herein.

The federal policy is reflected in PL 95-217, Section 301, which effectively pre-empts the use of ocean outfalls. It is also reflected in the regulations limiting ocean dumping under PL 92-532 (Marine Protection, Research and Sanctuaries Act). Wastewater sludges do not meet the current criteria requirements for granting a dumping permit. Interim permits may be issued to those municipalities currently dumping, allowing them to continue until 1981, with the condition that alternative plans be developed.

Given this policy situation, the local planners rejected an ocean disposal alternative. Thus the question whether ocean disposal is intrinsically more or less harmful to the environment than landside disposal options was never posed.

Because of the favorable economics of ocean disposal, and its importance to Boston as well as other coastal and near coastal cities, this section develops a policy history to provide as much perspective as possible. In addition, selected literature was reviewed to summarize the major water quality issues pertaining to sludge disposal in the ocean so that the policy restrictions can be seen against the background of known environmental concerns.

3. IMPLICATION OF SLUDGE ALTERNATIVES

As in Section 2, Section 3 is directed at the technology options for sludge management. In particular, the section develops the baseline case from which the impacts of federal policy shifts can be assessed.

Nine alternative technologies for sludge management are assessed (see Table 1) and costs estimated (see Table 2). The uncertainties involved in each technology lead to ranges in performance, which are reflected in the standard deviations shown. From the perspective of both the MDC and the federal decision maker, the ocean disposal options clearly have the lowest net costs; beyond that, the cost differences are generally conflicting or insignificant, for example, co-combustion appears to be third in national cost effectiveness, yet (because of low grant eligibility) is almost the most expensive for the local area.

Analyzing the costs of the alternatives in terms of their standard deviations* is also useful. The combustion and ocean options, for example, show relatively low standard deviations because these alternatives can be implemented in a relatively straightforward manner. In contrast, the composting and land application options show relatively high standard deviations because of uncertainties in how the sludge will be transported and used. Thus, further research to increase knowledge of procedures for sludge use could be beneficial for both the Boston area and the nation.

Environmental emissions for the alternative are also analyzed in this section. While published data on environmental impacts are lacking, particularly from the ocean options, emissions can be estimated and then compared to federal environmental standards. This analysis divides the alternatives into three groups:

- those that apparently comply with federal standards: incineration, pryolysis, co-combustion, composting and landfill;
- those for which federal standards are still to be issued: private site land application and land application by the MDC;
- those that cannot comply with present and projected standards: ocean discharge and ocean dumping.

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*Standard deviation is a standard measure of the variability around a mean.

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TABLE 1

SUMMARY DESCRIPTION OF ALTERNATIVES EVALUATED

Alternative 1: Incineration

A Sludge Dewatered to 40% Solids/151% Excess Air/11,080 Btu/lb
B Sludge Dewatered to 30% Solids/ 50% Excess Air/11,080 Btu/lb
C Sludge Dewatered to 26% Solids/ 50% Excess Air/11,080 Btu/lb
D Sludge Dewatered to 26% Solids/ 79% Excess Air/ 9,900 Btu/lb

Alternative 2: Pyrolysis

A Sludge Dewatered to 40% Solids/11,080 Btu/#/Afterburner @ 1,400°F
B Sludge Dewatered to 30% Solids/11,080 Btu/#/Afterburner @ 1,400°F
C Sludge Dewatered to 20% Solids/ 9,900 Btu/#/Afterburner @ 1,400°F

Alternative 3: Coincineration/Copyrolysis

A	Coincineration	30% Solids/427 Wet Tons/Day
B	Copyrolysis	30% Solids/427 Wet Tons/Day

Alternative 4: Ocean Discharge

A Separate Pasteurization/Local Discharge at Deer and Nut Islands
B No pasteurization/28,000-ft Line Connecting Nut and Deer Islands/36,000-ft Outfall Combined

Alternative 5: Ocean Dumping

A Separate Dewatering Nut and Deer Island/30-Mile Sea Haul
B Separate Dewatering Nut and Deer Island/70-Mile Sea Haul
C Combined Dewatering Nut and Deer Island/30-Mile Sea Haul
D Combined Dewatering Nut and Deer Island/70-Mile Sea Haul

TABLE 1 (Continued)

	Alternative 6: Composting
A	Compost/100% Distribution/No Landfill
B	Compost/ 50% Distribution/50% Landfill
	Alternative 7: Landfill
A	Dewater, O&M at $20 per Dry Ton
B	Dewater, O&M at $25 per Dry Ton
	Alternative 8: Land Application at Dispersed Private Sites
A	Regional Storage/120-Day Apply/53-Mile Pipe
B	Regional Storage/ 60-Day Apply/53-Mile Pipe
C	Regional Storage/120-Day Apply/76-Mile Pipe
D	Regional Storage/ 60-Day Apply/76-Mile Pipe
E	Regional Storage/ 60-Day Apply/129-Mile Pipe
	Alternative 9: Land Application at MDC-Owned Sites
A	5% Solids/120-Day Apply
B	5% Solids/60-Day Apply
C	25% Solids/120-Day Apply
D	25% Solids/60-Day Apply

TABLE 2

THE COST OF TECHNOLOGY OPTIONS*

	Mean		Standard Deviation	
Alternative	Total $/dry ton	Local $/dry ton to MDC	Total $/dry ton	Local $/dry ton to MDC
Incineration	111.22	57.79	7.25	6.96
Pyrolysis	118.92	64.40	11.40	11.40
Co-combustion	90.38	70.50	3.54	7.04
Ocean Discharge	26.05	10.45	12.32	1.61
Ocean Dumping	60.19	36.15	7.25	4.29
Composting	103.08	66.82	15.01	13.85
Landfill	116.47	92.44	9.40	3.56
Land Application (dispered private site)	114.64	45.24	33.31	8.74
Land Application (MDC owned site)	111.17	51.22	36.09	39.40

*Mean and standard deviation calculated from costs for cases listed in Table 1.

The local decision maker's primary consideration is whether an alternative will work, that is, whether an alternative is economically acceptable and whether emissions meet federal standards. Local cost and environmental risk tradeoffs among acceptable options are a secondary consideration based on the federal constraints. Ocean options illustrate this situation, and land application may also be an issue. Section 4 discusses the impact of changing conditions.

4. SENSITIVITY ANALYSIS AND STAGING OF SLUDGE ALTERNATIVES

The analysis in Sections 2 and 3 creates a baseline for analyzing sludge alternatives in the Boston situation, Section 4 uses this baseline to evaluate the impact of various changes in exogenous factors, including federal policies and environmental standards. A number of independent analyses are performed, and their results are described below.

1) Revenue Increase Increases in the revenues for the sale of compost, sludge or corn affect the attractiveness of the land use alternatives, particularly for the MDC. Revenues are reflected in net O&M costs, and each $1 increase in the sale of a ton of sludge or compost for land application (Alternatives 6 and 8) is equivalent to a $1 decrease in the net cost per ton. In a marketing study performed by the EPA, fertilizer values were estimated at $29.84 per dry ton, which, if this figure can be realized, could reduce the MDC's cost of land application to that of ocean discharge. An increase in corn price has a much smaller impact on the MDC-owned facility, however, and sludge pricing should only be attempted if sludge can be distributed free of charge in significant quantities to farmers.

2) Shifts in Energy Costs To assess sensitivity, the analysis assumes a doubling in energy costs. The net impact of energy price changes on the costs of combustion alternatives is generally small, with increased costs balancing increased revenues for power sales, except for the copyrolysis case in which net costs increase by about 50% (largely for power use in waste classification). For the noncombustion alternatives, the increase in costs when energy prices double is about $3 to $5 per dry ton in most cases, so that these options also appear to be relatively insensitive to energy costs.

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3) Increased Grant Eligibility for Co-combustion The basic co-combustion case (3A) has a net cost to the MDC of about $65 per dry ton. If the whole system is eligible for grants, and assuming solid waste handling produces no revenue, the cost to the MDC would drop to $25 per dry ton of sludge. With solid waste revenues at a reasonable level, such as $3 per ton of this waste (at a 10:1 mix), the system would turn a profit because, of course, the capital costs of the full system would be paid for at the 90% level by state and federal grants. Revenues would thus have to cover only operating costs and 10% of the capital share. Obviously, this situation would be beneficial to the co-combustion options.

4) Transportation Costs Several of the analyses evaluate the importances of transportation costs, which range from about 10% of the total for some options to over 90% for others. Transportation is responsible for much of the cost differences between alternatives and should be carefully analyzed.

5) Reductions in Dewatering Costs Sludge dewatering technology is an important factor in the effective operation of the combustion options and may be significant elsewhere. In addition, it is a major cost element by itself and an area in which technology is changing. A 30% reduction in the cost of reaching an equivalent solids level would lead to O&M cost reductions of $6 to $7.50/dry ton of sludge.

6) Costs of Pretreatment While only the roughest cost estimates are available for a pretreatment program, these costs to the MDC and industry combined would appear to be about $3.4 million annually. A program at this level would remove approximately 50% of the metals in the sludge. This reduction would have no impact on the suitability of sludge for ocean disposal (it would still not meet EPA's criteria) and would not be cost effective in a land application program. By purchasing additional land, and spreading sludge over a wider area the metal application rate at MDC sites could be decreased for approximately the same cost of implementing pretreatment.

7) Odor Control Hydrocarbon emissions and odors from sludge combustion could be reduced by the EPA and the Commonwealth of Massachusetts. This program would lead to constructing an afterburner for the sludge incinerator and would increase net costs for the system by about $6 per dry ton (about 6%).

8) Disinfection Another potential federal requirement would be to disinfect sludge discharged into the ocean or applied on land at private sites. This possibility, assuming the electron beam irradiation systems are used, is analyzed for three cases. The cost increase is about $10 per dry ton, and other disinfection technologies have potentially lower costs. Therefore, a disinfection requirement does not have a major impact on the ranking of alternatives.

9) Land Application Standards For land application of sludges, the EPA has proposed criteria containing stringent cadmium limits. The MDC would have three options for meeting these criteria: first, the MDC could reduce application rates below the agronomic optimum; second, the MDC could require pretreatment of the wastes to remove metals before they enter the sludge and finally, the MDC could apply at agronomic levels and monitor the crops for metal uptake. As mentioned above, reduced application rates are somewhat less expensive to the MDC and the nation than pretreatment. Monitoring costs are not assessed in this study, and the risk of high levels of metals uptake is not estimated.

10) Ocean Dumping and Discharge Standards The present standards allow dumping of sludge meeting certain standards for metals content; however, no conceivable pretreatment program could produce sludge meeting these standards, since a 99% reduction in cadmium content and a 90% reduction in mercury content would be required. EPA's regulatory posture would have to change significantly before ocean dumping becomes feasible.

The requirements for ocean discharge are somewhat different. At this point, ocean discharges must meet the best practicable technology (BPT) requirement, which demands that a sludge discharge meet the standards for secondary treatment effluent of 30 ppm 5-day biochemical oxygen demand and 30 ppm total suspended solids (TSS). Meeting these standards with sludge discharge is not now technically feasible.

11) Secondary Sludge The study focuses on primary sludge, since it is both a current problem and an area in which significant planning and design work have been done. The quantities of sludge, after implementing the proposed secondary and advanced treatment plants, may increase fourfold, probably affecting the feasibility of sludge disposal alternatives. For example, contraints on landfill capacity already exist, as do limits on the available space at Deer Island (where, for example, composting was proposed). Land for land application is also probably not available in Eastern Massachusetts on current sites. Particularly if reduced-rate application is attempted, pretreatment looks more attractive when secondary sludge is considered. Air quality may also be an issue, since the combined primary and secondary sludge incinerators would be a major source of nitrogen oxides (NO_x) and an emission offset for NO_x would be difficult to obtain in the Boston area. When a decision is made to construct the treatment plant, these are the constraints that affect secondary sludge management alternatives and form some of the major areas for analysis.

12) Hybrid Options If constraints such as the limits on secondary sludge use do apply, then developing more than one sludge management alternative may be desirable, especially if some options seem attractive, but are possibly too uncertain for a full commitment at present. Land application appears to be such an alternative, so a hybrid system was designed to assess the costs of partial commitment.

Nut Island sludge is presently more suitable for land application than Deer Island sludge because of its lower metals and salt content. The hybrid option, therefore, applies Nut Island sludge to the land while landfilling the sludge from Deer Island. As might be expected, the costs average between the costs of land application and landfilling. Transportation is the only major economic difference. Truck and rail transportation are used for the hybrid alternative, and pipeline is used for land application. Pipeline transport increases the total costs somewhat and greatly increases local costs because this form of transport requires large outlays of capital.

13) Delay and Staging The final, and perhaps the most important, issue addressed in this section is staging. The Clean Water Act sets specific compliance dates for facilities, and these dates are reflected in documents such as the MDC's Enforcement Compliance Schedule Letter. However, because of the changing nature of sludge regulations and technology, delaying commitment to a sludge management system may be desirable on both economic and environmental grounds. This section develops a decision tree designed to determine the advisibility of building the proposed incinerator now or waiting five years. This decision tree is also designed to aid the choice of the best option from among incineration, ocean discharge and land application. While the detailed estimates could, no doubt, be improved with further analysis, the key questions for this decision appear to be:

- what alternative is implemented in the interim period of delay and
- what is the probability that ocean discharge will be allowed?

The analysis assumes that the former question would be answered with "landfill" as the most expensive and most environmentally controlled option. This answer seemed a safe default for the interim period. The second issue then becomes paramount. If the probability that ocean discharge would be acceptable is over 10%, both the federal government and the MDC would be induced to delay commitment and choose temporary alternatives. The expected return from research on ocean impacts was evaluated and appears to be millions of constant 1975 dollars.

The study team does not intend to recommend to the EPA and the MDC that they delay their decision making, but suggests that the analysis be continued and that Congress and the EPA develop ways to use uncertainty, rather than ignore it. The proposed extra grants for alternative and unconventional technologies are one good example; commitments that are made by most jurisdictions before the technologies are fully tested has been a major problem. A program that spends billions of dollars on untried systems is inefficient, and if delay appears to make sense to individual communities, the nation as a whole might find delay worth considering. Otherwise, technologies that look good on the drawing boards, but that do not work in the real world, may be adopted; sludge incinerators, advanced treatment plants and even some secondary treatment technologies already appear to be affected. In some cases, attempts to force the technology may only lead to large boondoggles, and delay may be the rational option.

5. THE EFFECTS OF GOVERNMENTAL POLICIES ON SLUDGE MANAGEMENT PLANNING

In Section 5 the Sludge Case Study presents findings on the influence of different levels of governmental policies on sludge management planning on the local level. The MDC's efforts in the area of sludge management planning are examined as are the state's and the Regional EPA's role. Finally the influence of federal policy is analyzed.

Metropolitan District Commission

The MDC is the agency responsible for the expenditure of federal funds for the treatment and disposal of sludge in the study area. The two divisions within the MDC directly concerned with sludge matters are the Sewerage Division, which operates and maintains sludge treatment facilities, and the Environmental Planning Section of the Environmental Services Division. To date, the major sludge management planning studies have been conducted for the MDC by the consulting engineering firm of H&E.

The MDC has conducted or sponsored few pilot-scale studies on sludge treatment and disposal over the last eight years. It has cooperated with the NSF by providing space at the Deer Island facility for its sludge irradiation study. Although the MDC discharges both wastewaters and sludges into the ocean, no marine studies have been sponsored either on methods of disposal or on the impacts of disposal.* Recently (June 1977) the MDC contracted with Energy Resources Co. of Cambridge to perform a composting feasibility study. This study represents the first program ever sponsored by the MDC in the area of sludge management planning.

The general passivity of the MDC toward evaluating alternative sludge disposal options appears to reflect both the attitude of its planners as well as the historic role of the MDC in initiating and administering water pollution control programs. Historically the MDC has been a multipurpose public utility involved in maintaining and operating water supply, parks, roads, police and sewerage facilities.

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*As part of its application procedure for a variance from secondary treatment requirements, the MDC began conducting marine environmental studies in the fall of 1978.

The MDC has never been an "authority" and lacks the independent fiscal powers that typically characterize sewerage authorities. It cannot float a revenue bond without express authorization of the Legislature.

The MDC is developing an industrial waste management program designed to reduce the levels of metal-containing wastes introduced into its sewerage systems so as to reduce the potential for interference of sewage treatment performance and to reduce the levels of metals that contaminate sludge. However, the MDC has not yet promulgated a new sewer-use ordinance primarily because of the political opposition of the Legislature. The failure to promulgate and enforce a strong sewer use ordinance ensures the continued high level of metals found in Deer Island sludges and potentially limits the sludge use and ocean disposal options.

Based on the probable opposition of the Legislature and its control over the MDC budget, it is highly unlikely that the MDC could implement a land application option that required the purchase of land outside the MSD. Alternatively, the MDC appears to be in a very advantageous position to implement a composting option because it owns 15,000 acres of parkland. In addition, the MDC has potential access to thousands of acres of parkland from its 43-member communities. The MDC could require, for example, that each member community accept an amount of compost in proportion to its sewage flows.

State Government

The environmental functions in the state are organized into five departments under the Executive Office of Environmental Affairs (EOEA). These include the MDC, the Department of Environmental Quality Engineering (DEQE), Environmental Management, Food and Agriculture and Fishery and Wildlife.

The DEQE establishes standards of performance for both landfills and land application facilities. To date, the DEQE has developed only a sketchy policy on sludge spreading on soil. All programs that intend to spread sludge on land are now subjected to a case-by-case review before approval is granted.

The Department of Environmental Management through its Bureau of Solid Waste will probably play a major role in focusing the state's efforts on sludge disposal. This responsibility stems from the EPA's definition of sludge as a type of solid waste. A larger budget and more staff are anticipated if the Bureau's focus becomes statewide.

Although the Department of Food and Agriculture does not have regulatory authority in the area of sludge management planning, it does have a publicized interest in preserving agricultural lands, which have been declining in acreage over the last ten years at the rate of more than 20,000 acres/year. To the extent that municipal wastewater sludges can be spread on agricultural lands for purposes of growing crops, then this activity contributes to the preservation of agricultural lands. Furthermore it is possible, by selecting the landspreading option, to direct federal monies through EPA's construction grants program to subsidize a portion of agriculture in the Commonwealth. Neither EOEA nor the Department of Food and Agriculture has recognized and acted on this opportunity, nor have they participated in sludge management planning within the MSD.

The State Legislature has been indirectly involved in sludge management planning through a bill introduced in 1976 to establish a Commission on Organic Waste Recycling. The Commission was established by the Secretary of EOEA when the legislature failed to pass the bill. Support and members were from state agencies, the State Legislature and academic institutions. Alternative methods of sludge disposal were studied by two task forces. Each task force produced a report; one on land application of sludges and the other on composting techniques. The reports have been approved, and regulations based on the reports' recommendations should follow as part of a guideline effort.

Region I EPA

Region I EPA has been most active in the area of sludge management planning at the EIS level. It has been totally inactive at the research and development and demonstration levels. In particular, no studies have been sponsored, conducted or coordinated by Region I on the effects of wastewater or sludges on the marine environment.

Region I's EIS activities resulted from an MDC preliminary engineering report titled "A Plan for Sludge Management." The MDC plan considered treatment and disposal of primary and secondary sludges and used 1995 as its design year. After reviewing the MDC plan, the EPA independently developed its own sludge management plan. The EPA separated sludge management planning into two phases corresponding to a phase of primary sludge management and a phase of secondary sludge management. EPA included the primary sludge plan in its draft EIS in which the incineration option was recommended (the same option recommended by the MDC). Region I incorporated this plan for secondary sludge into its overall EIS for expansion of Deer and Nut Island facilities to secondary treatment.

Neither the MDC nor EPA's primary sludge management plans considered the composting process as an option.

A summary of the findings of the sludge study is shown below.

- EPA has usurped MDC's position as primary planner of sludge disposal facilities in Boston. Such action is not in accord with NEPA and was begun even before the MDC submitted a grant application for a sludge disposal project. Given the obvious reluctance of the MDC to undertake a "fair" analysis of alternatives, the EPA could have formally rejected the MDC effort and thereby laid the responsibility for any subsequent delay entirely onto MDC's shoulders.

- Region I's sludge management plan was more flexible than the MDC's, as it planned for the disposal of primary sludge only, thereby keeping an "open mind" on disposal of secondary sludge.

- The EPA, in recommending advanced incineration technology for primary sludge, did not acknowledge the technical uncertainty of this incineration option.

- In keeping its options open for secondary sludge disposal, EPA concluded that secondary sludge would be less contaminated with metals and would therefore be more amenable to soil application. The study team has found no basis in fact for that conclusion. It is even possible that secondary sludge would have a higher metal content than primary sludges.

- Although EPA considered heat-dried sludge for use as a fertilizer, it did not consider composted sludge.
- Although this study has shown that an MDC-run land application facility could be cost effective (in contrast to EPA's version of the landfarming option), the study team recognizes that the MDC would have serious difficulties in implementing the option because of the probable impeding influence of the legislature.
- The EPA has delayed the MDC sludge effort by ignoring the MDC sludge plan and maintaining its plan in draft form at least until December 1978. In so doing, another option, composting, has been shown in this study to be cost effective, and also in the interim the MDC has initiated a demonstration study.

Federal Policy Implications

The federal government has taken the roles of providing incentives and defining constraints on the actions of states and municipalities, so its policies have a major impact on local planning processes for sludge management. An evaluation of these policies and their local impact is described below.

Grant Eligibility

Privately-owned coincinerators are not eligible for federal funding under EPA's Construction Grants rules, nor are the O&M costs that would be incurred if a muncipality were to use the services of a private incinerator firm. It is recommended that, in the case of disposal options such as co-combustion, the construction grants rules be changed to allow a municipality to contribute capital for a portion of a private facility under the grants program, in return for partial ownership.

New Technologies

This study has found that the advanced incinerator recommended by Region I EPA and the MDC appears to be technically uncertain. In particular, little or no operations data are available at the local level to provide a base for local evaluation of this option. This information is urgently needed. If the information is not found to be available, then the EPA should take appropriate steps to prevent inefficient expenditures. If the operations data are more available than this study has found, the EPA through its technology transfer and clearinghouse functions should make these data available to municipalities. In either case the EPA should be collecting and analyzing all available operations data on advanced incinerators. The same efforts should be expended on all new technologies.

Pretreatment

In the 1977 amendments to PL 92-500, if toxic chemical wastes are deposited into the waste treatment facilities sludge, these wastes must now be pretreated, thus increasing the costs of sludge disposal.

Utilization options such as land application and composting would benefit the most if pretreatment of metals were carried out. If options such as land application demand pretreatment, which otherwise would be unnecessary, then the land application option should include the agency's pretreatment costs.

Standards for Land Application

The promulgation of final federal criteria for land application of sludge has been subject to continued national delays. Thus, supporting land application as a serious option becomes difficult when it is unknown whether a facility will be allowed to operate after standards are developed. To balance the uncertainties of the land application option resulting from EPA's delay in issuing final standards (for whatever reason), the EPA could make this option more attractive to the planner (even with uncertainty) by increasing the base federal subsidy from 75% to a higher percentage, or by assuming a portion of the municipality's financial burden caused by restrictive regulations.

Cost-Effectiveness

The evaluation process for systems funded under the Construction Grants Program requires that the most cost-effective and environmentally sound option be chosen. The cost-effectiveness guidelines, however, do not admit to uncertainty in costs. If a system that cost $100 with certainty were available, and another existed with an expected cost of $99 but with a significant chance of costs on the order of $1,000, the EPA would require the latter choice. In cases that are not as clear cut, but where uncertain technologies exist, the procedures will result in the choice of options with lower expected costs but higher risks. Legal uncertainties are equally difficult to consider in the analysis. The cost-effectiveness procedures should not attempt to assume that uncertainty does not exist, but allow this uncertainty in choosing individual systems to be considered explicity.

A second cost-effectiveness issue involves the determination of the most cost-effective and environmentally sound option. It is clearly conceivable that EPA would find land application to be most cost-effective, while the MDC would prefer incineration (or vice versa). The national cost-effectiveness goal is important, but local issues such as site location, perceived environmental impacts, and so forth, are also significant. There seems to be no obvious reason why EPA could not set the grant amount according to the cost-effectiveness criteria, but allow the local authority to build a more expensive option, if it desired to pay the incremental costs. For example, if EPA computed the capital cost of land application at $20 million and incineration at $25 million, EPA would provide a 75% grant for the lower-cost system ($15 million), but the local government could invest $10 million instead of $5 million and build an incinerator. Computing the grant on the most cost-effective option could simplify the evaluation process and would reduce federal control over local choice.

Deadline Requirements

In developing pollution control policies, Congress has set a number of significant deadlines. From the sludge management perspective, the most significant deadline is the requirement for secondary treatment under BPT, which was first set for July 1, 1977 and has recently been extended to July 1, 1983 for municipalities that meet certain conditions. Secondary treatment implies some acceptable means of sludge disposal, and construction delays lead to a need for fast action in choosing a technology and proceeding with design and construction. Primary sludge, of course, must be managed in an acceptable manner by 1981.

The analysis in Section 4 suggests that delaying final selection of a sludge disposal technology beyond the 1983 date may be desirable, given current information on the technologies and the potential for change. Delay may mean more expensive (but environmentally acceptable) interim solutions. However, if delay leads to sufficient cost reductions, it may be possible to demonstrate the advantages of such a delay and build at a latter date when more information has been gained. However, this scenario is not possible under the Clean Water program; delays are not an acceptable option, and it is very difficult to revise plans in light of additional data. It seems possible to develop an approach that would require performing a careful analysis and demonstrating significant total benefits before delay would be allowed, while retaining the administrative simplicity of the current approach.

On a related note, the costs of wastewater treatment have been rising quickly at a faster rate than the measures of inflation for the economy as a whole. The cost-effectiveness approaches required by EPA understate the costs of future O&M in their evaluation as follows:

1) The analysis is required to be in constant dollars, so uninflated O&M amounts are used.

2) Constant capital payments are also used, based on actual bond amounts. These, however, are in constant dollars and do not change over time.

3) To perform a constant dollar analysis, the capital payments in current dollars should be deflated by the inflation rate; conversely, to perform a current dollar analysis, the O&M payments should be inflated. Either way, O&M is understated with respect to capital.

The current procedure seriously affects the choices of engineers and local governments, and may lead to situations, as found with a number of sludge incinerators, in which municipalities fail to keep systems running because they could not plan for the true O&M costs under EPA's evaluation framework.

Ocean Standards

In response to the 'Ocean Dumping Law,' PL 92-532, final regulations and criteria for ocean dumping were promulgated January 11, 1977. Standards were set for ocean dumping permits and criteria were established that could not possibly be met by the sludges currently being ocean dumped. The law was amended in November 1977 by PL 95-153 which included an outright ban on all ocean dumping of sewage sludges by December 31, 1981. The new law has created a federal policy that eliminates ocean dumping as a disposal option without due consideration of local factors.

The study team believes that the present federal policy on ocean dumping of municipal wastewater sludges has two main deficiences.

1) The federal policy appears to have much more of a legal basis for its existence than a scientific one. The scientific features of the "ocean ban" policy are particularly vague and are not set within a broad qualitative or quantitative framework. The impression is left that were it not for the excesses of dumping in the New York bight area, little other scientific basis for the ban would exist. An additional need for a scientific framework exists if this policy is to be sensitive to information on negative environmental effects as well as to positive ones.

2) The decision by EPA to ban ocean disposal of sludge has been made without considering the environmental and economic aspects of alternative disposal modes. A risk-benefit analysis is needed, not only as a basis for justifying the present ban, but also for anticipating the environmental impacts of all options.

Additional Recommendations

Additional recommendations for improvement in sludge management planning at the national level appear below.

- The study team has concluded that it is possible to determine in an inexpensive manner the amount or percentage of metals contributed to the sewerage system by industrial and commercial dischargers. The method consists of sampling and analyzing the metal content of "raw" influent wastewater during holidays when the predominant commercial and industrial activities cease and then comparing these data (in concentration and loading terms) to data obtained during typical work week periods. By performing these studies under dry weather flow conditions and carefully choosing the appropriate holidays (such as Labor Day and Christmas), establishing the extent of point source contribution of metals should be possible. The study team recommends that EPA encourage municipalities to adopt such a method as part of their industrial wastewater survey procedures.

- EPA should obtain and quickly distribute information on the operational aspects of newly introduced technologies. This need is particularly acute in the case of the autogenous incineration option. At the moment, no organized body of data is available to those municipalities desiring to have such data to use as part of a decision process.

- The study team recommends that EPA develop information on the leachability of metals and other toxicants from ash (which results when sludges are incinerated). This information is needed to allow municipalities to environmentally assess site-specific hazards of ash disposal.

- EPA should update air pollutant emission factors for sludge incinerators, especially with regard to heavy metals and chlorinated hydrocarbons. This updating should be done in conjunction with alternative control methods such as afterburners and venturi scrubbers.

The answers to the complex questions have now become critical parts of the justification of EPA's proposed cadmium-sludge limits.

While the importance of these limits are recognized, this problem seems to pose little immediate threat to human health. As a result, the following approach is suggested. The uses of sludge should be restricted to nonhuman food chain crops, and limits should be removed from uses of sludges for growth of animal feed crops until after a long trial period. Trial periods of up to 10 years would probably be necessary to show the needed effects. By adopting this approach, EPA would remove many of the regulatory impediments to landspreading without increasing risk to humans.

- EPA should attempt to develop a mechanism for allowing mixing of a crop (such as corn) grown on sludge amended soils with crops grown on unamended soils. If a dilution of 1 part of sludge amended crop to 100 parts of non-amended crop could be achieved, no significant incremental addition of metal to the human food chain would occur.

Recommendations for Improvements in Local Sludge Management Planning

Recommendations for improvements in primary sludge management planning at the local, state and regional level appear below.

MDC

- The MDC industrial waste management program for surveying and monitoring the industrial and commercial contributions of metals to the sewerage system should be modified and accelerated. To obtain accurate information, one major modification is necessary: sampling and analysis should be (at least initially) under the control of the MDC, rather than the user.
- If the the composting option is adopted, the MDC should consider recommending to its member communities that each be required to accept and dispose of on parkland an amount of composted sludge equivalent to its population's contribution.

- EPA should clearly convey to municipalities the degree of accountability that is required, before award of construction grants, in maintaining and operating sludge treatment and disposal facilities. Additional emphasis is now needed because of the nationwide proliferation of disposal facilities such as sludge incinerators. A historical accounting of the number of sludge incinerators that have been abandoned because of operational problems should be made so that similar problems do not occur in a wholesale fashion with the new generation of sludge incinerators.

- The degree of environmental protection that is being required of the land application option is much greater than that employed in private-sector agricultural activites in which fertilizers and animal manures are routinely employed. The effects of this regulatory emphasis on the practice of landspreading wastewater sludges will probably be to limit the practice exclusively to municipal facilities.

- The human health effects caused by industrial exposure to cadmium serve as the bases of concern for potential toxic effects to persons consuming food grown on cadmium contaminated, sludge amended soils. Human health effects resulting from ingestion of such food crops, however, appear largely undocumented. Nevertheless, EPA has proposed cadmium limits that strongly govern sludge loading rates and, hence, the overall economic status of a major disposal and reuse mode.

  Some issues that are raised by EPA's regulatory posture are as follows.

  - Of the crops that concentrate cadmium, such as lettuce and swiss chard, how much lettuce must a person ingest before cadmium toxicity is evident?
  - If animals are fed crops grown on cadmium-contaminated soils, what levels of cadmium occur in the edible organ meat such as liver? How much liver must then be consumed to result in cadmium toxicity?

- The MDC should develop an in-house research and development capability with expertise in the marine environment sciences. This recommendation is needed because (1) the MDC currently has no scientific or technical capability in the marine area, and (2) its major treatment facilities currently discharge into the ocean. A contractor-oriented program could also be acceptable.
- The MDC should consider funding studies that document marine impacts of ocean disposal to build a case for or against such disposal in the event that EPA changes its ocean disposal policy. Both the fate and effect of ocean discharged sludge should be investigated.

State

- The MDC should begin to work, with respect to planning and decision making on matters of sludge and related issues, in closer contact with other departments within EOEA. The institutional arrangement of the MDC within EOEA is particularly suited for a broader MDC participation.
- State guidance material that goes beyond the minimal guidance provided by the DEQE letter (Appendix 5A) is needed, and specific technical and procedural requirements that would constitute reasonable and technically defensible standards for land application and landfill should be developed. The recommendations of the Commission on Organic Waste Recycling may provide the basis for such standards.
- The DFA should adopt an active role in overseeing the use of federal wastewater funds for agriculture. This action would contribute to its stated goal of preserving agriculture in Massachusetts.

Region I
EPA

- Region I should, as part of its EIS for primary sludge, include the composting option.

- Region I should closely examine those aspects of MDC's functions that may conflict with EPA's grant eligibility requirements for construction grants. In particular, conflicts arise because the MDC is unable to raise funds without undue legislative impedence. Such funds are needed to carry out its own research and demonstration programs, as well as to implement programs such as purchase of lands outside of the sewerage district (for example, landfill and land application sites). Without the ability to independently raise funds, the MDC cannot realistically evaluate certain options.

- Region I, in cooperation with EPA's Naragansett Laboratory, should increase its research activities (currently near zero) in the study area's marine environment. At a minimum, these activities should include an effort to coordinate all sludge- and sediment disposal-related studies. Since the present impacts of marine sludge discharges are largely undocumented, a scientific information base is needed, particularly in the event that the ocean disposal policy is changed.

- Region I (as well as all Regional EPA offices) should play a greater "technology transfer" role and provide its constituent municipalities with current and relevant information on topics of wastewater and sludge treatment disposal. This "clearinghouse" function is recommended in the Clean Water Act of 1977, Section 7.

1. INTRODUCTION

1.1 Purpose

This study evaluates the sludge management planning process in the Boston Metropolitan Area and includes the planning efforts needed to evaluate, select, locate and design sludge disposal facilities. Although this report uses Boston as a case study to evaluate sludge management planning, information and experience relating to both federal regulations and technologies can be directly transferred to other municipalities. Furthermore, the experience gained from dealing with local problems that appear unique to the local situation relates usefully and educationally to other municipalities, such as the coastal and near-coastal cities of New York, Philadelphia, Camden, N.J., San Francisco and Los Angeles, which are also facing complex sludge disposal decisions.

The objectives of this evaluation are to:

- improve the administration of water pollution programs in general and sludge management and planning in particular;
- upgrade the scientific and technical basis for decision making;
- ensure that federal sludge management programs are both cost effective and environmentally sound;
- provide analysis and understanding of the Boston experience that will improve sludge management planning both in Boston and other metropolitan regions and
- observe how national environmental policy affects sludge management planning in Boston.

1.2 Definition of the Problem

Sludge management planning is a problem complicated by a large number of factors affecting the decision-making process. These factors can be organized into three categories. The first category incorporates federal standards and laws, many of which are undergoing changes. The second category contains issues dealing with sludge treatment and disposal technologies. Not only are these technologies changing, but their efficacy or value is not always apparent to the planner. Finally, the third category contains issues that are specific to the local situation and that cause problems not easily answered by federal directives. These three categories are briefly described below and are discussed in greater detail in other sections of this report.

1.2.1 Federal Laws, Standards and Rules Governing Sludge Treatment and Disposal

Treatment and disposal of sludge is affected by many laws and rules promulgated at both the state and federal level. Federal laws in particular exert a strong influence on sludge planners by their presence as well as their absence. In the latter case, the uncertainty of impending rules causes difficulties for the planner. The most prominent laws and their applicability to specific disposal modes are shown in Table 1.2-1.

The sludge management planner must be able to assess the effects of such laws on all disposal options considered. Examples are shown below.

- The Clean Air Act provides concise limits for emission of pollutants such as particulate matter and sulphur dioxide, however, the short term ambient standard for nitrogen oxides is uncertain and has yet to be adopted by many regions of the country. If the more stringent of the proposed standards are adopted, the sludge incineration option may be precluded in certain air quality regions because of difficulties obtaining NO_x offsets.

TABLE 1.2-1

SLUDGE DISPOSAL LAWS

Law	Disposal Mode
Clean Air Act PL 95-95	Combustion alternatives such as incineration, pyrolysis
Ocean Dumping Act PL 92-532	Ocean dumping (barges)
Resource Conservation & Recovery Act PL 94-580	Land Filling Land Spreading
Federal Water Pollution Control Act Amendments of 1972 PL 92-500	
• Grant Eligibility Regulations Sec. 201	All
• Sec. 301	Ocean discharge (pipeline)
• Pretreatment Sec. 307 b & c	Landspreading
Clean Water Act of 1977 PL 95-217	All

- The Ocean Dumping Act has recently totally precluded ocean dumping of municipal sludges, thus, suddenly eliminating a long-established disposal option and requiring implementation of other disposal alternatives.
- The EPA has not yet promulgated standards of performance under the Resource Conservation and Recovery Act for either landfill or landspreading options, thus, planners must either assume the most stringent standards (and risk overdesigning) or delay the decision process and adopt an interim disposal method. Both choices could result in higher costs.
- Pretreatment Regulations, under Section 307 (b) and (c) of CWA, have not been comprehensively promulgated. The lack of federal action allowed municipalities to delay reducing heavy metal contamination of sludge, thus greatly diminishing the attractiveness of the landspreading and composting options.

Federal regulations, therefore, have eliminated one disposal method (ocean dumping) as well as created uncertainty regarding two other methods of disposal (landfill and landspreading), with the net effect of increasing disposal costs while, in some cases, delaying the implementation of effective environmental safeguards.

1.2.2 The Issue of Changing Technologies

With the elimination of the ocean dumping disposal option and the probable elimination of disposal of sludge by ocean discharge, three general modes of disposal remain: combustion, landspreading/composting and landfill.

Incineration is the most common form of combustion. Conventional forms of incineration are costly primarily because of high operating costs resulting from the consumption of large quantities of fuel oil. Newer types of incinerators are designed to operate without auxiliary fuel. However, little operating experience to judge this technology is currently available, therefore, this technology is uncertain.

Landspreading of municipal sludges has been performed for decades by many small mid-western municipalities. While this technique is well documented, concerns for the fate and effects of certain contaminants have developed. (The EPA is in the process of developing standards for regulating the metal contents of sludges). Additional documentation is being developed by the EPA on the environmental impacts of this disposal option. For those municipalities lacking agricultural engineering experience (the majority), this option is difficult to understand and initiate.

Composting is a sludge treatment method employing a form of landspreading for final disposal. While the composting process is not new, the engineering and scientific information about large-scale composting of sludge has only recently been developed, and the performance of the process has not yet been widely evaluated.

Landfill has been the most widely used form of sludge disposal primarily because of its low cost, but has also been the least regulated. However, this method will probably become more stringently regulated resulting in increased costs caused by requirements for environmental controls such as leachate treatment systems, liners and monitoring systems.

1.2.3 Issues Unique to the Local Situation that Affect Sludge Management Planning

The selection of a disposal mode by a municipality is often influenced by a number of distinctly local factors, such as the quantity and quality of sludge, geographical relationship between the point of sludge generation and the point of its disposal, land availability and costs, local and state regulations and the experience and knowledge of the planners.

Sludge Quantity

Because sludge is a product of wastewater treatment, the quantities produced depend on the type and size of the wastewater treatment facility. In general, the higher the degree of wastewater treatment, the more sludge generated per unit volume of wastewater. Accordingly, primary treatment plants produce relatively small quantities of sludge - approximately 0.3 dry tons for each million gallons of treated wastewater. Wastewater treatment plants that provide (biological) secondary treatment produce approximately 0.3 additional dry tons per million gallons of treated wastewater (total 0.6 dry tons). Advanced waste treatment systems that use physical and chemical methods to remove phosphorus and nitrogen generate approximately 0.4 additional dry tons or more for each million gallons treated (total 1.0 dry ton or more).

The large quantities of sludge associated with conventional wastewater treatment facilities create a major material handling problem and consequently the ultimate disposal of sludge becomes an urgent issue.

Sludge Quality

The chemical composition of sludge depends on sources and types of treatment and can influence disposal decisions in several ways.

- A high content of nitrogen and phosphorus will favor its use as a fertilizer.
- A high content of toxic chemicals such as cadmium and mercury in the sludge will preclude its use as a fertilizer and soil conditioner or its disposal by conventional landfill.
- A high thermal value (Btu/lb) will allow its use as fuel for incineration.
- The fertilizer elements that make sludge desirable for agricultural use will be a disadvantage in disposing of such sludge in landfills, since these substances, if not taken up by plants, may find their way into groundwater and surface water as pollutants.

Location and Transportation

The location of wastewater treatment plant may also influence disposal decisions in the following ways.

- The close proximity of some major cities to the ocean has strongly influenced sludge disposal through outfalls or ocean dumping.
- The lack of availability of space and suitable soils will favor disposal by landfill or incineration.
- The presence of agricultural activities will favor landspreading of sludges.
- The availability of land adjacent to the treatment plant will facilitate composting.

Regulations

State and local regulations will influence disposal decisions as indicated below.

- State public health standards may result in increased costs because of stringent requirements for stabilizing sludges.
- State and municipal regulations will influence landfill and landspreading site selection and availability.
- Local air quality regulations have been responsible for closing down newly constructed sludge incinerators.

Local Attitudes

Local attitudes and experience are important factors in decision processes, as shown below.

- A municipality with experience using a particular disposal method may tend to stay with the same option.
- A municipality with little experience using innovation and research and development may not explore new disposal methods.
- A municipality relying totally on engineering consultants as the major basis for expertise may have a different decision-making process from one in which the sewerage authority has in-house professional expertise.

1.3 Background of Sludge Management Planning in the Boston Area

1.3.1 Service Area

The Boston Metropolitan Sewerage District (MSD) presently includes 43 communities covering more than 500 square miles and provides service to about two million people. The MSD is currently served by two primary sewage treatment plants at Deer and Nut Islands in Boston Harbor. The two treatment plants provide primary treatment, including sedimentation, thickening (except at Nut Island), anaerobic digestion, and chlorination of effluents. The Deer Island Plant treats an average daily flow of 343 million gallons per day (mgd) from all or parts of 22 communities with a population of 1.3 million. Nut Island treats an average daily flow of 123 mgd (and is overloaded) from 22 communities with a population of approximately 700,000. Each plant discharges a combined effluent/sludge through individual outfalls from either side of President Roads into Boston Harbor. The Nut Island facility has been operating for 25 years, whereas the Deer Island Facility has been operating for only 9 years.

The MSD is expected to grow by an additional eight communities in future years. Both plants are scheduled to be upgraded to secondary treatment in compliance with PL 92-500. The MSD, which is operated by the Metropolitan District Commission (MDC), must by law accept any community, within a certain radius, that applies for membership in the MSD.

1.3.2 Role of the MDC

Since its creation in 1919, the MDC has been a multipurpose public utility whose responsibilities have included construction, operation and maintenance of the wastewater treatment and disposal system for the City of Boston and 43 municipalities in the Greater Boston Metropolitan Area. In addition, the MDC has operated and maintained a water supply, parks, road and police system. The MDC was never (and presently is not) an "authority" and has always lacked the independent fiscal powers that typically characterize sewerage authorities. Thus the MDC cannot float a revenue bond nor any kind of bond without express authorization of the Legislature. Local shares of the MDC's construction and operating costs are allocated among its member municipalities that remit their payments, not to the MDC, but to the State Treasury.

In short, the MDC has functioned as a wholesaler of sewer services to its member municipalities. Its utility function is designed for the convenience of its municipal members, and their political support has always been indispensable to whatever programs the MDC might propose. Even with the reorganization of environmental functions in 1972 when the MDC became one of five major departments within the Executive Office of Environmental Affairs, the MDC organization and powers were not greatly altered.

1.3.3 History

The location of wastewater outfalls as well as sewage treatment facilities in Boston Harbor and specifically on the harbor islands such as Deer, Nut and Moon Islands was undoubtedly influenced by such basic consideration as distance from urban centers and elevation. During the 1800's and before the construction of waste treatment facilities, raw sewage and street runoff was exclusively discharged without treatment at numerous locations in the Charles River and Boston Harbor. These discharges caused malodorous, anaerobic sludge-like sediments containing large quantities of organic matter to develop near the outfall. With the construction of wastewater treatment facilities at Moon and Nut Island in the early 1900s, sludge was produced directly as a result of wastewater treatment. This sludge can be defined as the solid material removed from sewage by a wastewater treatment process. A report by Hydroscience, Inc., which resulted from recommendations of the second Enforcement Conference on Pollution in Boston Harbor, concluded that 15 to 20% of the treated discharged sludge ultimately flowed back into Boston's Inner Harbor (Hydroscience 1971). The Inner Harbor has historically been subjected to pollution impacts affecting recreational activities, particularly body contact sports, and economic activities, namely fishing and shellfishing. Both impacts have been caused by high pollution levels most frequently measured in terms of coliform counts and oil. Pollution in the Inner Harbor has been attributed to one or a combination of three sources, namely: (1) combined sewer overflows directly entering the Harbor, (2) the wastewater effluent from the two treatment plants and (3) the digested sludge discharged at the Deer Island Facility. Also, industrial discharges possibly contribute to the Harbor's degraded condition. Hydroscience's conclusion concerning the fate and effects of discharged sludge has remained unchallenged until recently (Resource Analysis, Inc. 1976).

The MDC's current NPDES permit calls for the termination of discharges by May 1, 1980. The present method of sludge disposal was declared inadequate, by EPA as early as 1969 and after an agreement between the Massachusetts Division of Water Pollution Control and the EPA, the MDC began to investigate alternative methods of sludge disposal. The MDC contracted with the firm of Havens and Emerson (H&E) to prepare an alternative management plan for sludge disposal (H&E 1973). The same firm also performed an environmental impact assessment submitted to the EPA Region I in October 1974 (H&E 1974). The report was subsequently rejected by EPA. EPA Region I then hired EcolSciences to prepare a Draft Environmental Impact Statement (EIS), which was approved by the regional administrator in February of 1976 (EcolSciences 1976). A final EIS is due in 1978. At least a 2-year delay will have occurred between the Draft and Final EIS. While this delay was in part caused by the inclusion of the coincineration study, other reasons for dealy were internal to the EPA.

In addition to a wide range of public comments to the Draft EIS, a critical review was submitted in April 1976 by the "New England Consortium on Environmental Protection" under contract to the Massachusetts Executive Office of Environmental Affairs (EOEA). The review called attention to several important deficiencies of the Draft EIS, the most important of which were the analytical method, the attention given to certain disposal alternatives, in particular, the coverage of the land application alternatives, the approach to the heavy metals issue and the effectiveness of using industrial pretreatment to reduce metal emissions. Other deficiencies in the areas of energy, program integration with other pollution abatement programs and air and water quality impacts were also noted.

The National Science Foundation (NSF), the Council on Environmental Quality (CEQ), the EPA and the Office of Management and Budget (OMB) have initiated a case study of the planning process for the municipal wastewater treatment construction grants program in the Boston Metropolitan Area. A first phase preliminary analysis has been completed, and a second phase program is now underway. The second phase of this 2-phase program focuses on sludge management and addresses many of the same issues raised by the New England Consortium's review. This report constitutes the second phase of the NSF Boston Case Study.

1.4 Development of Study Area Chronology

A basic chronology of the study area has been developed to provide a historical documentation of all sludge-related events. The chronology provides a capsule view of 65 years of sludge management and planning efforts in the Boston Metropolitan Area. It provides a quick reference to show when various efforts occurred, what group conducted each study and how each group influenced and directed further studies.

Chronology of Sludge Management Planning in the Boston Metropolitan Area

1912	Lawrence Experimental Station began laboratory studies of activated sludge treatment of sewage.
1919	MDC was created, superseding the Parks Commission and the Water and Sewage Board.
1936	Special Commission consisting of members from MDC, Massachusetts Public Works and Public Health Department and the Boston Department of Health and Public Works produced House Document 1600, "Report of the Special Commission on the Investigation of the Discharge of Sewage into Boston Harbor and Its Tributaries." Among the recommendations were separation of combined sewers to prevent storm overflows and construction of primary sewage treatment plants on Deer, Nut and Moon Islands, possibly including incineration of sludge.
1939	Report by Harrison P. Eddy, Jr., and Samuel A. Greely (House Document 2465 of 1939) recommends primary plants at Deer, Nut, and Moon Islands with sludge barged to open sea for disposal.
1945	Massachusetts Legislature authorized the construction of a sewage treatment plant at Nut Island financed by a bond issue of $15 million.
1948	Sewer use ordinance for the MDC adopted. The ordinance was issued to protect the sewers from physical disruptions and explosions.
1949	Massachusetts Legislature authorized further financing for the completion of the Nut Island facility and construction of a sewage treatment plant at Deer Island.
1952	Nut Island Sewage Treatment Plant was completed and began operation providing treatment for the South Metropolitan Sewage District dry weather sewage flows. Sludge was discharged to the harbor via an outfall during ebb tides only. It was the first operating pollution abatement facility mandated originally by House Document 1600 in 1936.

1959 Massachusetts Legislature combined the North and South MSD including the area covered by the Boston Main Drainage System into a single MSD.

1963 Massachusetts Legislature created the Metropolitan Area Planning Council (MAPC).

1967 The New England River Basins Commission (NERBC) was created by an executive order and was authorized to prepare a water quality management plan for the Boston Harbor Drainage Area.

1968 The Deer Island facility was completed and began operating to treat dry weather flows from the North MSD. Sludge was diluted with effluent and discharged to the ocean via an outfall.

May 20 - First Federal Water Pollution Control Administration Enforcement Conference on adverse and public health impacts of wastewater inputs on shellfishing in Boston Harbor; "Conference in the Matter of Pollution of Navigable Waters of Boston Harbor and its Tributaries."

1969 April 30 - Second "Conference in the Matter of Pollution of Navigable Waters of Boston Harbor and its Tributaries." One of the recommendations of the conference was to have a consulting firm study the hydrology of Boston Harbor. Of special concern were the dispersion characteristics and mixing zones in relation to the disposal of sludge and effluent from Deer and Nut Islands.

1971 As recommended by the second Enforcement Conference, Hydroscience was hired and completed a "Final Report on Development of a Water Quality Model of Boston Harbor."

Influenced by the Hydroscience report, the MDC and the Massachusetts Division of Water Pollution Control (DWPC) signed a "Memorandum of Agreement," October 1, 1971. The Hydroscience Report indicated that further study was necessary and therefore the MDC was committed to conducting further studies by the Memorandum of Agreement. A preliminary report on alternatives for sludge disposal from Deer and Nut Islands was to be completed by April 1, 1972. An engineering report was to follow by April 1, 1973.

October 27, 1971 - The Third Enforcement Conference included a report from the Boston Harbor Coordinating Group of the NERBC, "Interim Report on Combined Sewer Overflows in Boston Harbor." The study was prepared by EPA Region I and the City of Boston, Mass. DWPC, MDC, MAPC and NERBC. The conference endorsed the recommendations of the Memorandum of Agreement, requiring the MDC to complete a preliminary sludge study by April 1, 1972 and a proposed implementation schedule by July 1, 1972.

Boston Harbor Pollution Task Force (BHPTF) was established by MDC to conduct the sludge study as required by the Memorandum of Agreement and the Third Enforcement Conference. The task force consisted of members from the MDC and the public.

A 1948 MDC sewer use ordinance amendment, which, in addition to providing protection for the sewer system as in the old ordinance, extended protection to the operation and performance of the sewage treatment plant, was promulgated.

1972 April - BHPTF submitted to the MDC "A Study of Alternative Methods of Sludge Disposal for the Deer Island and Nut Island Sewage Treatment Plants." After considering many alternatives for sludge disposal, the study recommended a further evaluation (to be covered in the engineering report required by the 1971 Memorandum of Agreement) of three options: land application, dewatering and incineration and wet oxidation.

July - The "Three Party Agreement" signed by the Massachusetts DWPC, MDC and EPA authorized the Eastern Massachusetts Metropolitan Area Study (EMMA) for long-term wastewater management and elaborated on the organization of the engineering report on sludge disposal plans mandated by the 1971 Memorandum of Agreement.

MDC was incorporated into the Executive Office of Environmental Affairs.

Two studies sponsored by MAPC were completed, "Boston Harbor Islands Comprehensive Plan" and "Alternative Regional Solutions for Sewerage Systems for the Boston Metropolitan Area", by Camp, Dresser and McKee (also a number of reports by consulting engineers for towns outside the MSD; see Kennedy, Phase II).

Congress passed the Federal Water Pollution Control Act Amendments of 1972 and the Marine Protection, Research and Sanctuaries Act. Congress had previously passed the Clean Air Act Amendments and Resource Recovery Act.

1973 March - The study, "Structural Evaluations and Ecological Observations in Boston Harbor" by TCE, Inc., found many of Deer Island outfalls clogged.

July - Massachusetts Clean Waters Act enumerated the responsibilities and powers of Massachusetts DWPC.

August - "A Plan for Sludge Management" by H&E was completed for the MDC. This engineering report was mandated by the 1971 Memorandum of Agreement and the 1972 Third Party Agreement. After reviewing the three alternatives chosen by the BHPTF study, H&E recommended a 2-phase plan for sludge management. Phase I would combine sludge from Nut and Deer Islands and incinerate it at Deer Island. The ash was to be disposed in a man-made lagoon on Deer Island. Phase II involved concentration and storage of secondary sludge at both islands and then combined incineration at Deer Island. Note that incineration was recommended by House Document 1600 in 1936.

1974 May - "Rules and Regulations for the Establishment of Minimum Water Quality Standards and for the Protection of the Quality and Value of Water Resources," promulgated by the Massachusetts DWPC included standards for sludge deposits, scum, oil and grease.

October - H&E submitted an "Environmental Assessment Statement for a Plan for Sludge Management" to the MDC as required by the EPA in accordance with Title 40, Part 6. The Environmental Assessment reviewed the economic and environmental considerations of the three management alternatives plus a no-action alternative.

1975 April 25 - As per EPA procedures for environmental assessments, a public hearing was held concerning the selected sludge disposal plan -- incineration.

June - Region I EPA hired EcolSciences to prepare an EIS for the sludge management plan. The decision to require an EIS resulted both from comments at the April public hearing and other public opposition to the proposed plan.

June - MAPC awarded a grant by EPA for a 2-year Areawide (208) Waste Treatment Management Study.

September 4 and November 10 - EPA sponsored two workshops concerning the EIS being prepared by EcolSciences.

Report to the National Commission on Water Quality of Boston Harbor and Charles River was completed by Process Research, Inc.

Sludge Fertilizer Marketing Survey was conducted by Development Planning and Research Associates.

October - The EMMA Study was finished, although the full report was not released until June 1976.

1975 Massachusetts legislature passed Chapter 814, which authorizes the MDC to carry out direct inspection of sewers in MDC-member communities. Chapter 814 provides for two types of sewer use permits: (1) those issued by the MDC to a member city; (2) those issued jointly by the MDC and the member city to an industrial user.

1976 January - The Commission on Organic Waste Recycling was established, chaired by Secretary of Environmental Affairs, Evelyn Murphy. The commission was charged with collection and analysis of information relative to disposal of selected organic wastes by application on agricultural or forest land. Current Massachusetts institutional arrangements and regulations were inspected, and a report was issued and recommendations were made in this regard.

1976 February 18 - A Public Hearing on Draft NPDES permit to MDC for the Deer and Nut Island treatment plants and combined sewer overflows was held. The new permit would replace the existing permits due to expire June 30, 1977. The draft permit (Federal Permit No. MA 0102351) included an implementation schedule for construction of projects of Steps 1, 2 and 3 facilities plans. (The permit and schedule satisfy Priority Items 1 through 15 of the EMMA Recommended Plan.)

February - EcolScience's Draft EIS of the Proposed Sludge Management Plan was approved by the Region I EPA.

July - Interagency Case Study Phase I Reports on the wastewater facilities planning process in Boston. This case study was undertaken to evaluate how the Clean Water Grant Program works to aid in the construction of municipal sewage treatment plants.

August - The new MDC discharge permit was issued. A major difference from the draft permit is that the compliance schedule was based on PL 92-500 with a completion date for all secondary facilities and sludge plans of July 1, 1977. Other requirements included in the draft permit were omitted. An Enforcement Compliance Schedule Letter (ECSL), which modified the completion dates with an extension through 1984 for upgraded primary treatment and July, 1985 for secondary treatment, was included.

September - A Public Hearing concerning the Annual Program Plan for Fiscal Year 1977 was held. This plan revised the Massachusetts priority ranking system for wastewater construction projects.

October - Resource Conservation and Recovery Act, which gives authority to the states to regulate landfills, was passed. Under Section 1008, EPA will develop criteria and guidelines for solid waste disposal including landfills and landspreading. Section 3001 provides for the identification and definition of hazardous wastes. The law will provide the information necessary to landspread sludges and other materials in an environmentally acceptable manner.

November - Stone and Webster completed a Waste Treatment Feasibility Study on coincineration for the MDC. This study was funded in response to comments of the Draft EIS. The findings of the Stone and Webster study will be included in the Final EIS. (Expected release of EIS - early 1978.)

1977 Environmental Impact Statements are underway on a number of major priority projects recommended in the EMMA Study.

April - Task force on Organic Waste Recycling submitted its report on land application of sludge and composting to the commission.

April - Beginning of NSF (Interagency Team) Boston Case Study of Sludge Management Planning by ERT.

May - A Conference on High Energy Electron Treatment of Municipal Wastewater Residuals was held. Reports were presented of the joint NSF-MIT-UNH irradiation project which had been underway at Deer Island since 1974. A 100,000 gpd electron research pilot facility was currently in operation.

August - ERCO (Energy Resources Co.) began a composting study for the MDC. The study consisted of two parts: a compost marketing study and a pilot composting facility at Deer Island. The pilot plant was currently successfully composting sludge from the Deer Island Treatment Plant. The marketing study indicated enthusiastic acceptance of the compost, "Metroloam" by park, public works and horticultural users.

November - Congress passed amendments to the Marine Protection, Research and Sanctuaries Act of 1972, including funding for research and other programs for F41978 and a legal ban on ocean dumping of sewage sludge after December 31, 1981.

November - EPA's long awaited Technical Bulletin, "Municipal Sludge Management: Environmental Factors" was published in the Federal Register. The Bulletin provided basic information on land application procedures and other disposal options. The information was provided primarily for designers, municipal engineers and others involved in selecting disposal options.

December - The 1977 amendments to the Federal Water Pollution Control Act were passed.

1978 MDC informed EPA that it will apply for a waiver of the secondary treatment requirement.

EPA released its "Draft EIS on the Upgrading of the Boston Metropolitan Area Sewerage System."

1.5 Study Approach

The major issues that complicate sludge management planning have been identified as those associated with (1) the disposal technologies and, in particular their uncertainties, (2) regulations and constraints they place on the planner and (3) the local situation itself. The study team's approach in this study was to analyze the issues by:

- carefully conducting a state-of-the-art assessment of each disposal technology and identifying its uncertainties;
- formulating a set of candidate disposal options that reflect their respective uncertainties and developing a range of costs that result from present-day regulatory constraints, technological uncertainties and local factors;
- performing a sensitivity analysis of each sludge disposal option when various costs and regulatory constraints are altered;
- developing a method for decision-making under conditions of uncertainty;
- analyzing the influence of governmental policy on local planning and
- recommending changes to improve sludge management planning.

This analysis consists of five sections with appendices. Section 2 analyzes the critical technological issues affecting sludge management planning. Major sludge treatment and disposal methods are evaluated and key process and institutional variables are identified. Section 3 takes the technical findings presented in Section 2 and formulates a set of candidate primary sludge management options. Primary sludge management options are emphasized because documented federal involvement in sludge management planning in the Boston area has been limited thus far to projected Phase I 1985 primary sludge planning. Detailed cost and environmental analyses are performed for nine basic disposal alternatives under existing technical and federal policy constraints.

Section 4 removes a number of constraints and poses a set of potential changes in costs, technologies and standards by examining the sensitivity of a particular sludge disposal option to changes in costs and standards. In addition, this section recommends a procedure allowing planners to make decisions under conditions of uncertainty. Section 5 presents the study team's findings on how different levels of governmental policies influence sludge management planning on the local level. Finally, Section 5 presents recommendations for improving sludge management planning on both local and national levels.

1.6 References

Havens and Emerson, Ltd. 1974. Environmental Assessment Statement for a Plan for Sludge Management. Cleveland, OH.

Havens and Emerson, Ltd. 1973. A Plan for Sludge Management.

Hydroscience Inc. 1971. Development of Water Quality Model of Boston Harbor. Westwood, NJ.

Resource Analysis, Inc. 1976. Scientific and Technical Evaluation of the Environmental Protection Agency's Wastewater Facilities Planning. Boston Case Study Phase I, Water Quality Considerations. Cambridge, MA.

2. EVALUATION OF TECHNOLOGY OPTIONS FOR SLUDGE DISPOSAL

2.1 Introduction

2.1.1 Purpose

This section provides a review and assessment of technology options for sludge disposal in Metropolitan Boston. For each of the disposal options considered, the technical issues with which a planner must deal to properly evaluate each option are discussed.

These issues generally include:

- capital and operating costs;
- reliability of system performance;
- environmental protection;
- public health;
- community attitudes and
- federal/state policy framework.

Different technology options generate different concerns with respect to each of the above issues. The approach taken in this study has been to document these concerns in as much detail as appropriate by reviewing the local planning documents, interviewing local planning personnel and attempting to provide a critical overview.

In reviewing a body of planning data and decisions that have emerged over a period of several years, a critical outlook is required. Thus, to the extent possible, the review team was instructed to examine all of the key assumptions and determinants of the planning process. As a result, the team found that the previous planners limited their scope of technology options and, thus, additional alternatives could be introduced. Also, the team found in certain cases that questionable assumptions having important cost implications were made about engineering details; therefore, this section emphasizes the exposure of these engineering details.

2.1.2 Approach and Technology Selection Process

Critical technological issues affecting sludge management planning are discussed in this section. Major sludge-handling alternative technologies are described, and key process and institutional variables are identified. The specific technologies reviewed in this section will be formulated into total system sludge treatment and disposal alternatives in Section 3.

Throughout this study, the Boston situation provides a real-world basis for comparing alternative technologies and investigating the sludge management planning process as it is influenced by federal water pollution control regulations. Local planning studies are reviewed, and, to the maximum extent possible, data, presented in these reports, on facility sizing, costs and emissions are used in this study after verification, if necessary. Because documented federal involvement in sludge management planning in the Boston area has thus far been limited to the projected Phase I, 1985 primary sludge situation (described in the following section), the major emphasis of this study will be to analyze the planning process leading to the recommended Phase I facilities. Phase II facilities dealing with secondary sludge will not be emphasized.

As part of an evaluation of the sludge management planning process, the impact of institutional and technological uncertainties must be considered. Institutional and process variability can result in significant discrepancies between planning documents and real-world performance and costs.

Alternative plan costs and performance characteristics have been presented and compared by Havens and Emerson, Ltd. (H&E) in its 1973 report (H&E 1973) and in the EPA Draft Environmental Impact Statement (EIS) (EcolSciences 1976) as single-value numbers or quantities. In reality, project costs and performance characteristics in such preliminary planning documents are based on numerous assumptions. Although these assumptions are often made using insight of past experience, cost and performance estimates are subject to error, bias and, most importantly, variability. Actual cost and performance will normally fall somewhere within a range of values. To extend the previous analysis, a best-case through worst-case range has been developed on plan costs and performance characteristics.

The purpose of this study is neither to select the best action for sludge management in the Boston area nor to do another EIS. One goal is to evaluate how technological uncertainties can influence the planning process. To that end, a range of project cost and performance characteristics (that is, best-case, design-case and worst-case) for each of the major sludge handling technologies will be illustrated (see Section 3). Some technologies such as pyrolysis, coincineration and ocean discharge are analyzed in more detail than originally in the Draft EIS for primary sludge, because the Final EIS may also expand on these and other options.

It is not within the scope of work of this Boston Case Study to provide a detailed development and selection of the most cost-effective Phase II (secondary) sludge management plan for Boston. Region I EPA has contracted a consultant to perform a separate EIS on Phase II facilities. However, the manner in which Phase I alternatives interface with Phase II planning is discussed in Section 3 as part of the sensitivity analysis of each major technology alternative. The importance of assessing technological uncertainties as part of the planning process can be demonstrated with primary sludge quantities, for later extension to primary plus secondary sludge quantities.

Sludge management planning in the Boston area is particularly complex. The Boston area is confronted with the dual problems of (1) the immediate replacement of the existing primary sludge disposal practice and (2) the development of a suitable plan for disposal of future quantities of secondary sludge (from, as of yet, undefined secondary treatment facilities). The EPA has decided to split the EIS process for sludge management between these two aspects. In other cities, where existing primary sludge disposal is adequate, at least until secondary facilities are added, or where entirely new secondary plants are constructed, a single sludge management planning process/EIS is all that is required.

The sections that follow examine the important technical and scientific issues and, in particular, the uncertainties that influence each sludge treatment and disposal alternative. Some of the issues affect all technologies, and these are discussed in Section 2.2. Other issues are specific to a particular technology and are discussed under appropriate treatment and disposal alternatives presented in Section 2.3 (Combustion Alternatives), Section 2.4 (Land Alternatives) and Section 2.5 (Ocean Alternatives).

Technical and scientific issues related to each of these specific treatment and disposal alternatives are identified and their significance revealed through the following analyses. First, a concise process description is presented and technical uncertainties exposed for each of the three groups of alternatives. Second, a literature review is presented, emphasizing either local or national literature, depending on the particular alternative. Third, technology specific considerations are explained, including air and water quality considerations, design criteria and uncertainties. Fourth, the impact of primary sludge management planning on secondary sludge issues is discussed.

2.2 Sludge Management Issues

This section considers issues that influence all the basic technological alternatives for sludge treatment and disposal that are evaluated in this chapter. Sludge quantities, sludge composition and transportation costs will affect all technologies, although perhaps not uniformly. These factors and associated uncertainties are discussed below.

2.2.1 Projected Sludge Quantities

Review of Previous Studies

One of the most crucial parameters in any sludge management study is the projection of design sludge quantities. However, future sludge quantities are subject to great variability because they depend on the service area population, the per capita solids and flow contributions, nonpoint sources when combined sewers are used, industrial and commercial sources and the performance of wastewater treatment processes. In developing a sludge management plan, these variables must be extrapolated from existing information or assumed, based on experience in other cities.

Sludge quantities were originally projected in 1973 by H&E for Year 1995 conditions of primary and secondary sludge at Deer and Nut Islands and for Year 1985 primary sludge conditions. H&E projected 1985 Phase I primary sludge quantities were used in the Draft EIS for comparing alternatives. Metcalf and Eddy (M&E) (1976) also made population and flow projections for the EMMA study that have implications for projected sludge quantities different from those projected by H&E. Finally, Kennedy Engineers, as part of the Boston Case Study, has generated for the EMMA study area a number of alternative wastewater treatment strategies that result in a range of sludge quantities (Kennedy 1977).

Table 2.2-1 presents a summary of population and sludge quantity projections for recent years and key future design years, assembled from various reports. Table 2.2-2 presents a summary of Year 2000 sludge quantities projected for the various Kennedy Engineers alternatives, briefly described in Appendix A. The Kennedy Engineers Alternative II corresponds to the recommended EMMA study shown in Table 2.2-1.

TABLE 2.2-1

POPULATION AND SLUDGE QUANTITY PROJECTIONS

Site	MDC 1972	MDC Fiscal 1975-1976	H&E 1985	H&E 1995	EMMA 2000
		Serviced Population			
Deer Island	1,345,000	1,346,000	1,460,000	1,551,000	1,460,000
Nut Island	625,000	634,000	820,000	959,000	675,000
Satellite Plants	0	0	0	0	305,000
Total	1,970,000	1,980,000	2,280,000	2,510,000	2,440,000
		Flow (mgd-ADWF)*			
Deer Island	321	343	-	390	400
Nut Island	123	127	-	210	130
Middle Charles (AWT)**	0	0	0	0	31
Upper Neponset (AWT)**	0	0	0	0	25.2
Aberjona	0	0	0	0	0
Total	444	470	536	600	586.2
	Sludge Projection (average daily dry sludge solids - lbs)				
Deer Island					
Thickened primary	166,000	172,000	250,000	259,000	-
TWAS†	0	0	0	215,000	-
Total Deer Island	166,000	172,000	250,000	474,000	478,000
Nut Island					
Primary	121,000	97,000	189,000	215,000	-
TWAS†	0	0	0	130,000	-
Total Nut Island	121,000	97,000	189,000	345,000	210,000
Total Middle Charles	0	0	0	0	72,000
Total Upper Neponset	0	0	0	0	58,000
Total Aberjona	0	0	0	0	0
Total Raw Sludge Solids to Treatment and Disposal (avg. lbs/day)	287,000	269,000	439,000	819,000	818,000

*mgd-ADWF - Average Dry Weather Flow

**AWT - Advanced Wastewater Treatment

†TWAS - Thickened Waste Activated Sludge

Sources: MDC 1976; H&E 1973; M&E 1976.

TABLE 2.2-2

SLUDGE QUANTITY PROJECTIONS FOR KENNEDY ENGINEERS (KEI) ALTERNATIVES

	Year 2000 Average Daily Sludge Production (thousands of pounds per day)					
KEI Alternative	Middle Charles	Upper Neponset	Neponset River	Nut Island	Deer Island	Total
I A	0	0	0	134	194	328
I B	0	0	0	141	219	360
I C	0	0	0	186	239	425
I D	0	0	0	186	353	539
II (EMMA)	72	58	0	210	478	818
III A	0	0	0	290	478	768
III B,C	44	36	0	210	478	768
III D	0	0	0	210	478	688
III E	0	0	80	210	478	768
III F	0	0	80	210	478	768
III G	0	0	0	210	478	688
III H	0	0	130	210	478	818
III J	0	0	0	198	266	464
III K	0	0	0	198	266	464

Source: Kennedy Engineers, Inc. 1977.

The range of sludge quantities shown in Tables 2.2-1 and 2.2-2, corresponding to different design years and different wastewater treatment alternatives, indicates the complexity of determining the design basis for comparison of sludge management alternatives.

From the data presented in Table 2.2-1, note that the sludge quantity projections by H&E for the Deer and Nut Islands plants exceed the quantities expected at those plants under the EMMA plan. The difference is mainly the result of the diversion of a large portion of the Nut Island sewage flow to satellite treatment plants under the EMMA plan. The H&E plan is also based on a greater serviced population in 1995 than the Year 2000 population projected for EMMA. Furthermore, Kennedy Engineers show (Table 2.2-2) that EMMA-estimated total (II) sludge quantities differ by a factor as large as 2.5 from the base case (IA).

Sludge Quantities Used for Comparing Alternatives

As stated previously, the detailed anaysis of sludge management planning in the Boston area presented here is primarily related to the planning process to date, which includes completion of the Draft EIS on Phase I primary sludge facilities. A breakdown of the projected 1985 sludge quantities used in the Draft EIS is provided in Table 2.2-3. The quantities from Table 2.2-3 are also shown on the process flow diagram in Figure 2.2-1.

For reference when necessary, a process flow diagram for projected 1995 primary and secondary quantities is shown in Figure 2.2-2. The process flow diagrams shown in Figures 2.2-1 and 2.2-2 are consistent as they are both based on original H&E data.

The sludge quantities shown in Table 2.2-3 and in Figures 2.2-1 and 2.2-2 are used in this case study for evaluating alternative technologies for treatment and disposal of sludge from Deer and Nut Islands. These values were derived from the Draft EIS and the H&E report. To demonstrate the impact of technical uncertainties and evaluate the planning process, the indicated data is an acceptable basis. Note that current sludge management planning, as evidenced in the Draft EIS, is proceeding with sludge quantity projections that are somewhat inconsistent with the EPA approved basin plan, which is the recommended EMMA plan.

TABLE 2.2-3

1985 PROCESS STREAM CHARACTERAZATION

PHASE I PROJECT*

Item	Average Day					Maximum Day				
	DSS[+] lb/day x 10^3	VSS[++] lb/day x 10^3	% vol	% solids	mgd	DSS[+] lb/day x 10^3	VSS[++] lb/day x 10^3	% vol	% solids	mgd
Primary Solids										
Deer Island	257	179	70	5.0	0.62	450	313	70	4.5	1.20
Nut Island	189	145	77	5.4	0.42	312	239	77	5.0	0.75
Thickened Solids										
Deer Island	250	174	70	7.0	0.43	437	305	70	6.5	0.81
Nut Island			None					None		
Bypassed Solids										
Deer Island	25	17	68	7.0	0.04	43	30	70	6.5	0.08
Nut Island	19	15	79	5.4	0.04	32	25	78	5.0	0.08
Solids to Digester										
Deer Island	225	157	70	7.0	0.39	394	275	70	6.5	0.73
Nut Island	170	130	76	5.4	0.38	280	214	76	5.0	0.67
Solids after Digestion										
Deer Island	137	69	50	4.2	0.39	240	121	50	4.2	0.73
Nut Island	80	40	50	2.5	0.38	132	66	50	2.5	0.67
Solids to Filters										
Deer Island										
Total	148	79	53	6.6	0.27	178	98	55	6.1	0.34
Raw	25	17	68	7.0	0.04	43	30	70	6.5	0.08
Digested	123	62	50	6.3	0.23	135	68	50	6.3	0.26
Nut Island										
Total	91	51	56	4.0	0.27	111	65	59	4.0	0.33
Raw	19	15	79	5.4	0.04	32	25	78	5.0	0.08
Digested	72	36	50	3.8	0.23	79	40	50	3.8	0.25
Combined Plants										
Total	239	130	54	5.3	0.54	289	163	56	5.2	0.67
Raw	44	32	73	6.6	0.08	75	55	73	5.7	0.16
Digested	195	98	50	5.1	0.46	214	103	50	5.0	0.51
Filter Cake with Chemicals										
Total	255	129	50	30**	0.10**	312	162	52	30**	0.13**
Ash	126					150				

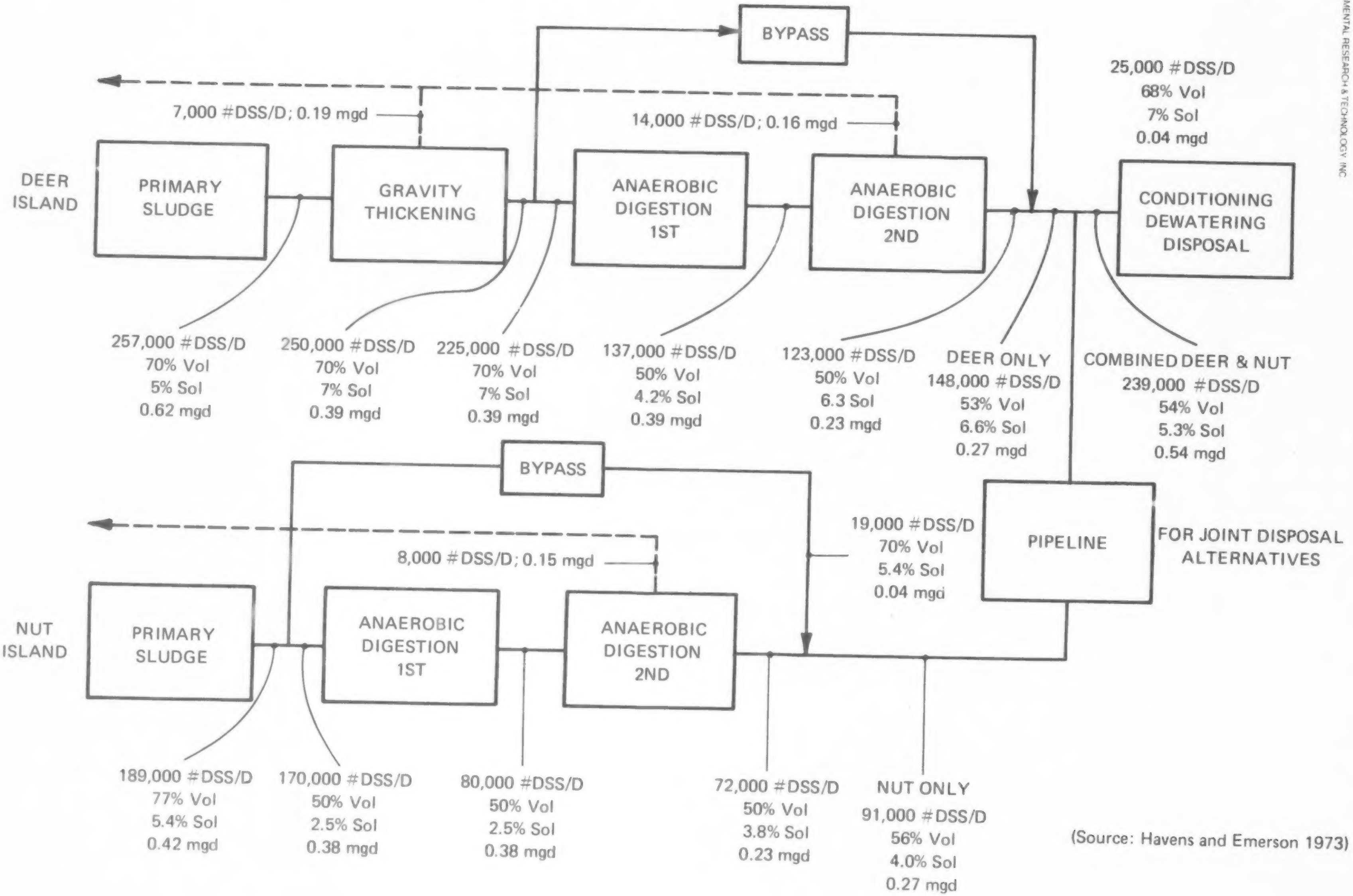
*Maintaining anaerobic digestion at Deer and Nut Islands plants with primary treatment expansion (Reprinted from Table N-2 of the Draft EIS.)

**Modified to agree with projected heat balances.

[+] DSS = dry suspended solids

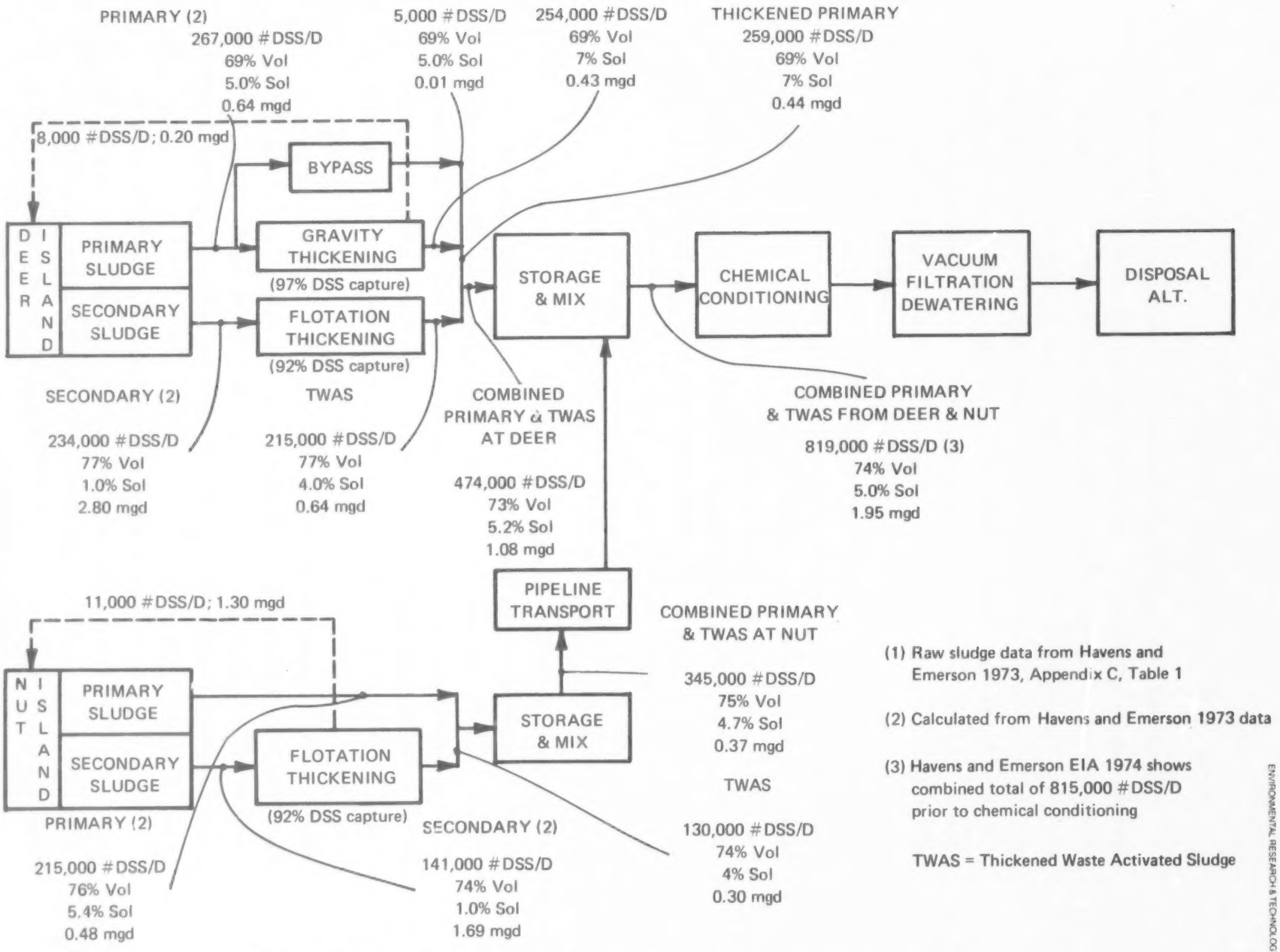
[++] VSS = volatile suspended solids

Source: H&E 1973.


DEER ISLAND
PRIMARY SLUDGE
GRAVITY THICKENING
ANAEROBIC DIGESTION 1ST
ANAEROBIC DIGESTION 2ND
BYPASS
CONDITIONING DEWATERING DISPOSAL
7,000 #DSS/D; 0.19 mgd
14,000 #DSS/D; 0.16 mgd
25,000 #DSS/D 68% Vol 7% Sol 0.04 mgd
257,000 #DSS/D 70% Vol 5% Sol 0.62 mgd
250,000 #DSS/D 70% Vol 7% Sol 0.39 mgd
225,000 #DSS/D 70% Vol 7% Sol 0.39 mgd
137,000 #DSS/D 50% Vol 4.2% Sol 0.39 mgd
123,000 #DSS/D 50% Vol 6.3 Sol 0.23 mgd
DEER ONLY 148,000 #DSS/D 53% Vol 6.6% Sol 0.27 mgd
COMBINED DEER & NUT 239,000 #DSS/D 54% Vol 5.3% Sol 0.54 mgd
PIPELINE
FOR JOINT DISPOSAL ALTERNATIVES
NUT ISLAND
PRIMARY SLUDGE
ANAEROBIC DIGESTION 1ST
ANAEROBIC DIGESTION 2ND
BYPASS
8,000 #DSS/D; 0.15 mgd
19,000 #DSS/D 70% Vol 5.4% Sol 0.04 mgd
189,000 #DSS/D 77% Vol 5.4% Sol 0.42 mgd
170,000 #DSS/D 50% Vol 2.5% Sol 0.38 mgd
80,000 #DSS/D 50% Vol 2.5% Sol 0.38 mgd
72,000 #DSS/D 50% Vol 3.8% Sol 0.23 mgd
NUT ONLY 91,000 #DSS/D 56% Vol 4.0% Sol 0.27 mgd

(Source: Havens and Emerson 1973)

Figure 2.2-1 Process Flow Diagram of Projected Sludge Quantities 1985 Phase I Primary Sludge


PRIMARY (2)
267,000 #DSS/D
69% Vol
5.0% Sol
0.64 mgd
5,000 #DSS/D
69% Vol
5.0% Sol
0.01 mgd
254,000 #DSS/D
69% Vol
7% Sol
0.43 mgd
THICKENED PRIMARY
259,000 #DSS/D
69% Vol
7% Sol
0.44 mgd
8,000 #DSS/D; 0.20 mgd
BYPASS
DEER ISLAND
PRIMARY SLUDGE
SECONDARY SLUDGE
GRAVITY THICKENING
(97% DSS capture)
FLOTATION THICKENING
(92% DSS capture)
STORAGE & MIX
CHEMICAL CONDITIONING
VACUUM FILTRATION DEWATERING
DISPOSAL ALT.
SECONDARY (2)
234,000 #DSS/D
77% Vol
1.0% Sol
2.80 mgd
TWAS
215,000 #DSS/D
77% Vol
4.0% Sol
0.64 mgd
COMBINED PRIMARY & TWAS AT DEER
474,000 #DSS/D
73% Vol
5.2% Sol
1.08 mgd
COMBINED PRIMARY & TWAS FROM DEER & NUT
819,000 #DSS/D (3)
74% Vol
5.0% Sol
1.95 mgd
PIPELINE TRANSPORT
11,000 #DSS/D; 1.30 mgd
NUT ISLAND
PRIMARY SLUDGE
SECONDARY SLUDGE
FLOTATION THICKENING
(92% DSS capture)
STORAGE & MIX
COMBINED PRIMARY & TWAS AT NUT
345,000 #DSS/D
75% Vol
4.7% Sol
0.37 mgd
TWAS
130,000 #DSS/D
74% Vol
4% Sol
0.30 mgd
PRIMARY (2)
215,000 #DSS/D
76% Vol
5.4% Sol
0.48 mgd
SECONDARY (2)
141,000 #DSS/D
74% Vol
1.0% Sol
1.69 mgd

(1) Raw sludge data from Havens and Emerson 1973, Appendix C, Table 1

(2) Calculated from Havens and Emerson 1973 data

(3) Havens and Emerson EIA 1974 shows combined total of 815,000 #DSS/D prior to chemical conditioning

TWAS = Thickened Waste Activated Sludge

Figure 2.2-2 Process Flow Diagram of Projected Sludge Quantities 1995 Phase II Primary Second Sludge

2.2.2 Projected Sludge Composition

The composition of 1985 primary sludge produced at Deer and Nut Islands can be estimated by characterizing the composition of the current digested sludge and adjusting these values for the projected increases in residuals production. Because the sources of metals in the MDC service area have not been clearly identified, it is not possible at this time to project future trends in metal contributions to the sewerage system. Therefore this analysis assumes that the concentration of metals and nutrients in future sludge solids (ppm-dry weight) will remain constant. Possible reductions in metals resulting from the implementation of pretreatment standards are not considered in these projections. The anticipated effect of industrial pretreatment on primary sludge composition will be discussed separately. These assumptions avoid controversial projections of increases or decreases in industrial wastewater contributions within the MDC sewerage districts. An additional estimation of the quantity and quality of secondary sludges is included.

Heavy Metals

Previous studies on sludge management options for Boston have included analyses of the heavy metals composition of Deer and Nut Islands sludges. Because a variety of sampling periods was used, the data summarized in Table 2.2-4 does not present a consistent representation of sludge composition. The Draft EIS on sludge management does include a summary of two and a half years of treatment plant operating data. However, because of the high variability in reported sludge compositions, longer-term averages provide a better basis for planning purposes. The approach used for this study, therefore, is to compare average sludge compositions over the last four years to the historic plant records presented in Table 2.2-4. A summary of the collected data is contained in Appendix 2A.

Table 2.2-5 is a summary of a simple statistical analysis of the last four years of operating data (July 1973 to June 1977). The actual comparison of the historic data from Table 2.2-4 and the calculated means (July 1973 to July 1977) from Table 2.2-5 appears in Table 2.2-6.

TABLE 2.2-4

METAL CONTENT OF DEER AND NUT ISLANDS DIGESTED SLUDGES AS REPORTED BY VARIOUS SOURCES

(all values: ppm dry weight)

Source	Range	Chromium	Copper	Cad-mium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic	# Samples
Deer Island											
Plant Records*	MAX	3,000	1,800	110	660	640	165	4,800	16	10	-
	MIN	500	730	53	170	93	12	990	3	4	-
	MED	1,200	1,100	81	440	350	72	2,700	9	6	-
Havens & Emerson Ltd.**	MAX	620	920	36	180	141	72	2,000	6	3	1
	MIN	390	580	18	170	74	68	680	3	<0.3	1
Ecolsciences†		947	1,600	82	452	329	47	2,818	8.8	6.6	~20
MDC, Sept. 1975		1,787	1,923	49	110	219	30	3,041	4.2	-	1
Nut Island											
Plant Records*	MAX	580	1,100	200	730	2,170	81	4,200	71	14	-
	MIN	200	580	28	160	310	34	1,100	8	2	-
	MED	300	870	85	410	530	48	2,800	14	5	-
Havens & Emerson Ltd.**	MAX	220	830	11	380	67	3	1,600	8	5	1
	MIN	140	720	6	220	48	3	1,400	7	<0.4	1
Ecolsciences†		218	711	61	434	318	41	1,522	8.4	10.3	~20
MDC, Sept. 1975		232	880	23.3	174	310	31	1,736	4.5	-	1

*Historic plant records before 1972.

**Two samples composited Nov. 13 to 15, 1972, and Nov. 29 to Dec. 1, 1972.

†1973 to 1975, Table N-5, EcolSciences 1976.

Source: H&E 1973; EcolSciences 1976.

TABLE 2.2-5

VARIABILITY OF METALS CONTENT OF DIGESTED SLUDGE AT DEER AND NUT ISLANDS TREATMENT PLANTS

Fiscal 1973-1977

(all values: ppm dry weight)

Metal	Maximum		Minumum		Monthly Mean		Standard Deviation		Standard Deviation Monthly	
	DI*	NI**	DI*	NI*	DI*	NI**	DI	NI	DI*	NI*
Chromium	5,352	727	167	18	1,234	208	888	145	72	70
Copper	5,774	1,936	147	136	1,779	628	1,266	370	72	59
Cadmium	146	180	10	2	70	36	32	34	46	94
Lead	1,007	1,136	55	58	436	382	243	228	56	60
Nickel	657	1,558	88	35	307	282	131	271	43	96
Silver	275	145	14	5	64	47	51	31	80	66
Zinc	9,108	2,436	833	172	3,316	1,271	1,868	483	56	38
Mercury	12.2	50	1.6	0.2	6.0	6.3		8.4		130
Arsenic	14.3	42	2.5	2	6.3	8.7		9.0		103

*Deer Island, period of record July 1973 to June 1977 (40 monthly samples).

**Nut Island, period of record July 1973 to June 1977 (22 to 41 samples).

Source: MDC Fiscal 1974-1977.

TABLE 2.2-6

COMPARISON OF FISCAL 1973-1977 SLUDGE COMPOSITION TO HISTORIC RECORDS

(all values: ppm dry weight)

	Deer Island		Nut Island	
Metal	Monthly Mean (Fiscal 1974-1977)	MAX/MIN/MED* (Historic)	Monthly Mean (Fiscal 1974-1977)	MAX/MIN/MED* (Historic)
Copper	1,779	1,800/730/1,100	628	1,100/580/870
Chromium	1,234	3,000/500/1,200	208	580/200/300
Cadmium	70	110/53/81	36	200/28/85
Lead	436	660/170/440	382	730/160/410
Nickel	307	640/93/350	282	2,170/310/530
Silver	64	165/12/72	47	81/34/48
Zinc	3,316	4,800/990/2,700	1,271	4,200/1,100/2,800
Mercury	6	16/3/9	8.4	71/8/14
Arsenic	6.3	10/4/6	9.0	14/2/5

Source: Historic from H&E 1973, monthly mean from MDC Fiscal 1974-1977.

*The purpose of this analysis was to determine whether significant changes have occurred in sludge composition in the last four years. Inherent problems exist when comparing median values to mean values, therefore, maximum, minimums and medians are included.

At Deer Island, mean values over the last four years closely resemble those for historic data except for copper. A trend to increasing copper concentrations can be deduced from the fact that the fiscal 1973 to 1977 average approaches the maximum value previously recorded. A substantially different trend is observed at Nut Island. Except for those for lead, silver and arsenic, the 4-year averages resemble the minimum historic values rather than the medians, which may indicate a reduction in metals influent to the treatment plant.

This analysis is limited since it does not attempt to quantify the variability of reported sludge composition other than the simple statistical analysis included in Appendix 2A. In addition to the variability in the sampling and analytical procedures, contributions from street runoff and intermittent industrial discharges also could influence the variability of sludge composition.

Contribution from Street Runoff

A considerable portion of the Deer Island drainage area is served by combined sewerage. According to the EMMA study and the MDC's Annual Report on Deer Island, 65% of the contributing population and 23% of the sewered area is served by combined sewers. Note that much of the combined system is located in the industrialized sections of Boston, Cambridge and Somerville. On a loading basis, industrial land uses are the highest contributors of heavy metals in street surface runoff (Pitt and Amy 1973). If a quantity of the street surface metal loading is not lost in combined sewer overflows, part of the monthly variations in Boston's sludge composition may be due to climatological effects. Lead is one metal in particular that would be a sensitive indication of street runoff.

Intermittent Industrial Discharges

Because of the industrial nature of Metropolitan Boston, both Deer and Nut Island receive considerable quantities of industrial wastewater pollutants. Unlike domestic flows, which follow a measurable monthly, weekly and diurnal pattern, industrial flow follows a more random pattern based on local market fluctuation, process equipment operations, accidental spills and equipment maintenance. Although the attendant flows may be small when compared to domestic contributions, the large mass contributions of specific pollutants may cause fluctuations in wastewater quality and subsequently, in sludge composition. According to the MDC, industrial contributiona of metals to the collection system discharging to Deer Island treatment plant supply somewhat greater than 50% of the total metal load. This information is preliminary and based on a comparison of the heavy metals present in the influent wastewater during the work-week in relation to that present during Sundays and holidays such as Labor Day (Guarciariello 1977).

1985 Primary Sludge Metals Composition

As shown in Table 2.2-5, the monthly composition of digested sludge is highly variable, even when observed over four years [these values may be reported as a range equal to one standard deviation (see Appendix 2A)]. Since the dry-weight concentrations of metals are assumed to remain the same, the 1985 metal loading will increase only in proportion to sludge quantities. Loads calculated based on 1985 sludge quantities are shown in Table 2.2-7. Note that the loadings are based on monthly mean values, not annual averages.

Estimated Secondary Sludge Composition

Upgrading the treatment plants to secondary biological treatment will produce additional residual solids. It is therefore important to consider whether the selected primary treatment and disposal option will be feasible for secondary sludges. One means of assessing this is by estimating the heavy metals content of the secondary sludges.

The removal efficiency of primary and secondary treatment plants with respect to heavy metals is highly variable. To estimate secondary sludge composition at Deer and Nut Islands, literature values for secondary and primary removal capability were obtained (Burns and Roe 1975). The following equation permits a computation of secondary sludge load from primary sludge load and removal efficiencies.

TABLE 2.2-7

DAILY METAL LOADINGS: 1985 DIGESTED PRIMARY SLUDGE*

	Deer Island** (lb/day)			Nut Island† (lb/day)		
Metal	Mean		Standard Deviation	Mean		Standard Deviation
Chromium	180	±	130	19	±	13
Copper	260	±	190	57	±	34
Cadmium	10	±	5	3	±	3
Lead	65	±	35	35	±	20
Nickel	45	±	20	26	±	25
Silver	10	±	7.5	4	±	3
Zinc	490	±	280	120	±	44
Mercury	1	±	1	1	±	1
Arsenic	1	±	1	1	±	1

*Digested sludge before dewatering.

**Based on 148,000 lbs dry suspended solids (DSS)/day and Table 2.2-5.

†Based on 91,000 lbs DSS/day and Table 2.2-5

Source: ERT estimates.

Sample Calculation for Chromium at Deer Island:

$$\underset{\text{(from Figure 2.2-1)}}{\text{lbs DSS/day}} \times \underset{\text{(from Table 2.2-6)}}{\text{ppm dry weight}/10^6} = \underset{\text{(Table 2.2-7)}}{\text{lbs metal/day}}$$

$$148{,}000 \text{ lb/day} \times 1{,}234 \text{ ppm dry}/10^6 = 180 \text{ lb/day chromium}$$

$$L_s = L_p\ (S/P - 1)$$

where L_s is the secondary sludge load (lbs/day)
L_p is the primary sludge load (lbs/day)
S is the secondary plant removal efficiency
P is the primary plant removal efficiency

The estimated secondary sludge loads are presented in Table 2.2-8. These results indicate that the quantity of projected 1985 metals in secondary sludge will be approximately the same as that found in present-day primary sludge. In 1985, primary and secondary solids generation at Deer Island will be approximately the same (H&E 1973). Therefore, metals concentrations in secondary and primary sludges will be equivalent. At Nut Island secondary solid generation will be somewhat less than primary solids (H&E 1973). In 1985, the metal concentrations in Nut Island secondary sludge may be greater than that in primary sludge.

Comparison of Metals in MDC Sludges with Those of Other Cities

The concentration of potentially toxic metals such as cadmium, mercury, nickel, copper, zinc, lead and chromium in MDC sludges has important implications for several sludge disposal options, especially when sludge products are distributed to private users such as home gardeners or privately-owned farms. Programs in which sludge is distributed to private users allow only limited control over the rate at which potentially toxic metals are applied to crops. For example, such users may not follow good agronomic practices and may add excessive amounts of these sludges to acid garden soils. This practice could lead to the entrance of metals into vegetables and subsequently could lead to the direct introduction of metals into the human diet. Employing a labeling requirement and specifying the desired sludge quality on the basis of metal concentrations could reduce this potential risk.

The Origin of Metals in Sludge

Metals occur in close association with the suspended solids fraction of wastewater and, as a result, tend to concentrate in the sludges. In general, the more efficient the suspended solids removal

TABLE 2.2-8

ESTIMATED DAILY METAL LOADINGS IN SECONDARY SLUDGE

Metal	L_P Digested Primary Sludge-1985* (lb/day) DI†	NI††	S/P Secondary/Primary Removal Efficiency**	$L_S = L_P(S/P-1)$ Secondary Sludge Metal Loadings (lb/day) DI†	NI††
Chromium	180	19	1.8	140	15
Copper	260	57	2.2	310	68
Cadmium	10	3	2.1	11	3
Lead	65	35	1.6	40	21
Nickel	45	26	3.3	105	60
Silver	10	4	-	-	-
Zinc	490	120	1.9	440	110
Mercury	1	1	1.4	0.4	0.4
Arsenic	1	1	-	-	-

*From Table 2.2-7.

**Burns and Roe 1975.

†Deer Island

††Nut Island

process, the greater the concentrating effect in sludges. The resulting level of metals in sludge is not only related to the type and degree of wastewater treatment, but also to the nature of metals sources. For example, metals found in sludge may have originated from at least three sources, including (1) the raw water supply, (2) industrial point sources and (3) street runoff in systems with combined sewers.

In the previous section the levels of metals in Deer and Nut Island sludges have been reviewed and analyzed. In this section, the quality of Deer and Nut Island sludges is compared to recommended limits as well as sludge composition data obtained from other municipalities. This comparison is designed to provide insight into the level of pretreatment that may be required before certain municipalities can reduce metals to levels allowing sludges to be used as soil conditioners and fertilizers by the home gardener. The use of sludge for home gardening represents the greatest public health risk. Later, Section 2 will show that the level of metals now present in MDC sludges does not preclude its use on a centralized MDC-run facility where specific agricultural procedures can minimize the hazard of the entrance of metals into the food chain.

At the present time neither the Commonwealth of Massachusetts nor the EPA has published a standard of sludge quality in terms of concentration units. However, the U.S. Department of Agriculture (USDA) has recommended metal concentrations in sludges on a part per million (ppm) dry weight basis for its use in home gardens. Table 2.2-9 shows the recommended levels that meet the stringent standards of the USDA. In addition, sludge composition data, which show that MDC primary sludges contain more than twice the level of cadmium recommended for home garden use, are provided for Deer and Nut Island as well as other municipalities. The levels of copper and nickel also exceed these limits. Secondary sludges from the Blue Plains Treatment Plant in Washington, D.C. contain very low levels of metals and generally meet the USDA recommendations. Note that Washington is a less industrialized city than Chicago, where sludge has a correspondingly higher level of metals. Chicago's MSD industrial pretreatment program has reduced the heavy metal content of Calumet STP digested sludge, although cadmium still exceeds the recommended limit.

TABLE 2.2-9

CONCENTRATION OF HEAVY METAL IN MUNICIPAL SLUDGES COMPARED TO VARIOUS RECOMMENDATIONS

(all values: ppm dry weight)

	Boston			Chicago (Calumet STP)					
Metal	Deer Island	Nut Island	Boston Flow Weighted	1972	1974	Wash. D.C. (Blue Plains)	Sommers*	Purely Domestic*	USDA†
Chromium	1,230	210	850	1,100	790	-	2,620	50	-
Copper	1,780	630	1,370	900	280	1,000	1,210	250	1,000
Cadmium	70	36	58	100	54	20	110	5	25
Lead	440	380	420	1,800	490	-	1,360	-	1,000
Nickel	310	280	300	200	80	100	320	25	200
Silver	60	50	56	-	-	-	-	-	-
Zinc	3,320	1,270	2,580	3,500	2,800	2,000	2,790	750	2,500
Mercury	6	6	6	3	2.2	-	-	2	-
Arsenic	6	9	7	-	-	-	-	-	-

*Somers 1977. Mean value of 200 sludge samples.

**EPA 430/9 - 76-009, observed in sludges from newer suburban communities.

†R. Chaney et al. EPA 430/9-76-009, April, 1976.

Nitrogen

The nitrogen (N) content of Deer and Nut Islands digested sludge is summarized in Tables 2.2-10 and 2.2-11, respectively (MDC Fiscal 1974-1975). The data base is the same as that used for the analysis of heavy metals composition, namely, the last four complete years of operating data. For anaerobically digested sludge, total kjeldahl nitrogen (TKN) is a measure of the total nitrogen in sludge. For Deer Island the nitrogen content is 0.16% on a wet-weight basis, while for Nut Island the content is 0.13%. A further breakdown into NH_4^+ and organic-N (ORG-N) fractions provides estimates of the ratio of soluble/particulate nitrogen. These estimates are approximate because some organic nitrogen may be soluble. At Deer Island the ratio of NH_4^+/ORG-N is 0.44, while at Nut Island the ratio is 0.95. Apparently the digesters at Nut Island are more effective in converting organic nitrogen to ammonium. Possibly, the higher metal concentrations or chlorides in Deer Island sludges are inhibitory to the first-stage acid forming bacteria.

Both H&E and the EMMA study projected that by 1985 the quantity of solids in the raw wastewater influent at both treatment plants will be greater than that observed today. For purposes of this study, the following assumptions are made:

1) the ratio of NH_4^+/ORG-N remains the same and
2) the concentration of nitrogen (dry-weight) in the sludge will remain the same.

As a result, the nutrient load from the digesters will increase, while the nutrient content is assumed constant. The loading estimates are shown in Table 2.2-12.

TABLE 2.2-10

NITROGEN IN DEER ISLAND DIGESTED SLUDGE
(all values as nitrogen)

Variable	1974	1975	1976	1977	Mean
Digester Flow, mgd*	0.308	0.282	0.323	0.302	0.304
Total % Solids	3.5	2.96	2.4	3.5	3.1
TKN,** mg/ℓ	1,641	1,561	-	1,529	1,577
TKN, lb/day	4,218	3,673	-	3,854	3,915
TKN, % of total solids	4.8	5.3	-	4.4	4.8
NH_4^+, mg/ℓ	406	449	-	606	487
NH_4^+, lb/day	1,044	1,057	-	1,527	1,209
NH_4^+, % of total solids	1.2	1.5	-	1.7	1.5
ORG-N, mg/ℓ	1,235	1,112	-	923	1,090
ORG-N, lb/day	3,174	2,616	-	2,327	2,706
ORG-N, % of total solids	3.6	3.8	-	2.6	3.3

*mgd - million gallons per day

**TKN - Total kjeldahl nitrogen

Source: MDC Fiscal 1974-1977.

TABLE 2.2-11

NITROGEN IN NUT ISLAND DIGESTED SLUDGE

(all values as nitrogen)

Variable	1974	1975	1976	1977	Mean
Digester Flow, mgd*	0.202	0.261	-	0.160	0.21
Total % Solids	2.7	1.9	2.1	2.2	2.1
TKN,** mg/ℓ	-	1257	-	914	1086
TKN, lb/day	-	2738	-	1220	1979
TKN, % of total solids	-	6.6	-	4.2	5.4
NH_4^+, mg/ℓ	-	614	-	432	523
NH_4^+, lb/day	-	1337	-	554	946
NH_4^+, % of total solids	-	3.2	-	2.0	2.6
ORG-N, mg/ℓ	-	643	-	482	563
ORG-N, lb/day	-	1401	-	644	1023
ORG-N, % of total solids	-	3.4	-	2.2	2.8

*mgd - million gallons per day
**TKN - Total kjeldahl nitrogen
Source: MDC Fiscal 1974-1977.

TABLE 2.2-12

CURRENT AND PROJECTED PHASE I DIGESTED SLUDGE - NITROGEN LOAD

Variable	Deer Island		Nut Island	
	Current	1985	Current	1985
Digester Flow, mgd*	0.30	0.27	0.21	0.27
Total % Solids	3.1	6.6	2.1	4.0
TKN,** mg/ℓ	1,580	3,170	1,130	2,160
TKN, lb/day	3,920	7.140	1,980	4,870
TKN, % of total solids	4.8	4.8	5.4	5.4
NH_4^+, mg/ℓ	490	990	550	1,040
NH_4^+, lb/day	1,210	2,230	960	2,340
NH_4^+, % of total solids	1.5	1.5	2.6	2.6
ORG-N, mg/ℓ	1,090	2,180	590	1,120
ORG-N, lb/day	2,710	4,910	1,030	2,520
ORG-N, % of total solids	3.3	3.3	2.8	2.8

*mgd - million gallons per day

**TKN - Total kjeldahl nitrogen

Source: ERT estimates

2.2.3 Transportation Considerations

Introduction

It is inevitable that the recent public concern regarding treatment of wastewater and the resulting stringent disposal standards will bring about a dramatic increase in the quantities of residual materials. These materials, in the form of liquid or dewatered sludge, will have to be disposed of in a safe and preferably beneficial way to permit full use of resources. Since, in most cases, the sludge-producing facility is located away from the disposal facility (such as landfill or cropland), transporting the sludges from the point of production to the point of disposal becomes necessary. Therefore, the possible transportation modes for liquid or dewatered sludges and the related cost factors will play significant roles in the overall planning and cost-benefit considerations contemplated for any new facility.

There are four basic modes of sludge transporation that have been and are being used. These modes are:

1) truck transportation,
2) barge transportation,
3) rail transportation and
4) pipeline transportation.

One mode of transportation could be used exclusively for sludge transfer. In general practice, however, modes of transportation are used in combination to form a chain of transport from the producing facility to the disposal unit.

Description of Transportation Processes

Truck

Truck transportation is considered the most flexible form in regard to the relative locations of the producing facility and the disposal point. The only limiting factors are the existence of a well-developed route system and restrictions on road loading and routing. The basic transportation unit consists of a truck and trailer or a cistern. The trailer has to be fitted to transport dewatered sludge or ash with a minimum of leakage or spillage. The logistics of truck transport may call for purchase of a truck and trailer fleet, operating as part of the overall facility. However, economic conditions may favor contracting the trucking operations.

Barge

Sludge production facilities located near waterways or the sea can use barge transport. Liquid sludge can be conveyed from the production facility to the barge terminal and pumped into the barge holds. Dewatered sludge or ash can be transported to the terminal via a truck and discharged into the barge holds, or it can put in containers. The containers can then be transported to the barge, loaded in a piggy-back system and unloaded at the point of debarkation for further transport to the point of disposal. Parameters such as sludge consistency and ultimate disposal mode must be considered before the barge is equipped with internal loading and unloading systems. For example, barges transporting sludge for disposal at sea have to be equipped with devices permitting quick unloading of either liquid sludge, dewatered sludge or ash. Barges used for conveying and unloading sludge at a terminal for further conveyance via other modes of transportation have to be equipped with devices permitting a quick and efficient method of unloading. The logistics of barge transport may call for purchase of barges and contracting of towing services or for contracting the entire barging operation.

Rail

The feasibility of sludge transportation by rail depends on the avaibility of track between the points of sludge production and disposal. This mode of transportation is not as flexible as truck transport and may require capital outlays to construct additional track at the points of loading and unloading. Rail transport has an advantage over truck transport because of the amount of sludge that can be transported with a unit train and the corresponding reduction in manpower requirements. The cars will have equipment permitting quick discharge of the contents at the point of disposal. Special facilities may have to be constructed at the point of disposal to accept the sludge and store it for later disposal. These facilities may include: a pumping station, a pipeline and storage piles for dewatered sludges or, finally, trucking of ash residue for final disposal.

Since a large inventory of hopper and tank cars exists within the railroad industry, rail transport normally would be contracted for the entire operation, avoiding capital outlays for the purchase of the rolling stock. The operating costs would include rental fees for the cars, locomotives, track, switching fees and down-time fees for loading and unloading. In contracting such operations, the unit trains can be subleased for other uses during the return trips or during the times when no activity is possible at the loading and unloading points. Because rail haul structure is very complicated and depends on geographical location as well as haul distance and type of material, the advantages of the unit train operation as applied to rail transport economics must be considered. These economics may dictate purchasing the hopper or tank car fleets and leasing the locomotives, track and other facilities mentioned previously.

Pipeline

Transportation of solids suspended in liquid has been practiced in the United States for many years. The types of materials transported include coal and limestone slurries, goldmine tailings, iron concentrate and sewage sludge. Concentration of solids vary from as little as 1% to above 50%. Because of this range of solids concentrations, there are wide variations in the hydraulics of flow, power requirements, pipeline life expectancy and the economic impacts of pipeline transport. Pipeline is the most rigid of the transportation modes discussed here. Once the disposal point has been selected and the pipeline route chosen, long-range operation of the disposal program is necessary in view of the inability to vary the route and capacity of the pipeline. The amortized cost of the capital expenditures as well as operating cost of the pipeline should compare favorably with other modes of transportation to be economic. Parameters such as provision for purchase or long-term leases of the right-of-way, protection of the pipeline against damage by the forces of nature or man, proper locations for the main and booster pumping stations and environmental aspects of pipeline rupture must be considered. However, once the pipeline is constructed, its operation is then independent of negative factors such as weather, traffic slowdowns, highway accidents, derailments or maritime accidents.

Economics of Transportation

The major factors influencing the economics of sludge transportation are the sludge characteristics, the distance between the point of sludge production and the point of ultimate disposal and the contractual aspects of the transportation modes selected for the site-specific sludge disposal system (see Appendix 2B for further discussion of these factors).

These factors and other site-specific considerations will have a major effect on the overall cost of sludge transportation. The available literature contains numerous examples of attempts to generalize the comparative pricing structure and site-specific pricing of a particular mode of transportation. Realizing the need for unifying and standardizing the procedures for estimating transportation costs for any sludge disposal system, the EPA has contracted with Culp, Wesner, Culp, Clean Water Consultants, for a sludge transport study. The purpose of this study is to "develop a method of calculating transport costs for each mode using basic parameters such as gallons of fuel, operator manhours, operating miles, and similar factors." The study is still in a draft form and has not been published. Figure 2.2-3 shows some general trends and basic comparative transportation costs for the four modes of sludge transport. This figure has been prepared from two recent publications (Camp, Dresser and McKee 1976; EPA 1974c). However, the figure attempts to generalize the costs of transport and the actual site-specific costs may vary extensively when a particular set of circumstances, inherent in a particular transport mode and local conditions, is considered in the estimate.

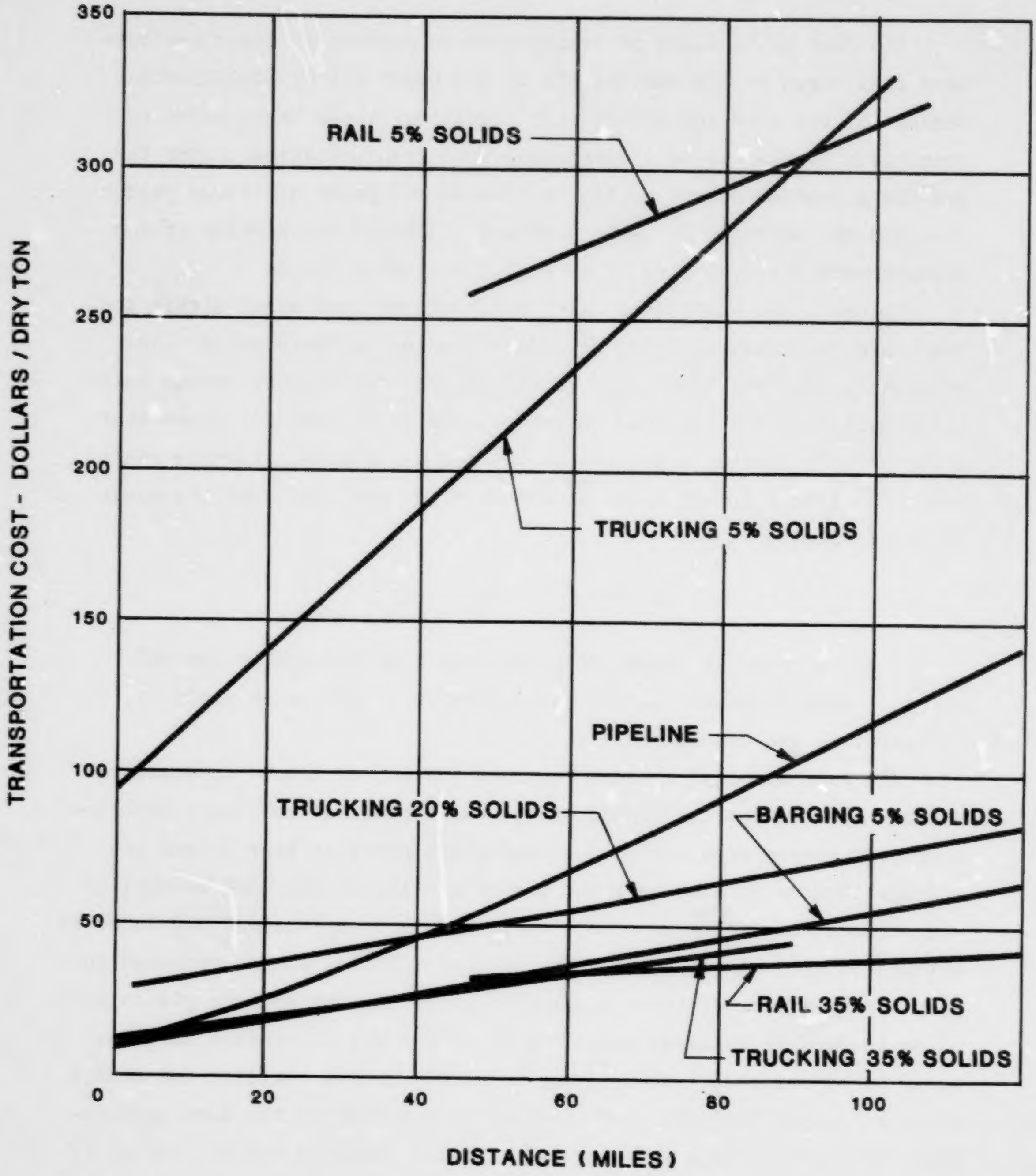


Figure 2.2-3 Comparative Transporation Costs

Transportation Modes in the Study Area

The four basic modes of transportation previously described have been considered by H&E and the EPA in the Draft EIS by EcolSciences. Because of the site-specific Boston situation, these basic modes of transportation had to be incorporated into transportation-trains to provide a transportation continuum between the point of sludge production and the point of ultimate disposal. A brief description of the transportation-trains used in each of the studies follow.

Figure 2.2-4 identifies major agricultural land areas within the state and the transportation corridors leading to these areas. The railroad routes are identified in the figure; the highway system basically parallels the railroad corridors, and it is safe to assume that major pipeline routes would follow the highway system. Barging routes identify major disposal areas at Sandwich, on the Cape, and the ocean disposal location.

H&E Transportation-Trains

Three methods of sludge disposal were comtemplated in the H&E report: land disposal, either for agricultural use or in landfill; incineration and wet oxidation.

The land disposal schemes involved the use of liquid or dewatered sludge. The scheme for liquid sludge was a proposal to create pipeline transport system from the sludge production point at Deer Island to storage lagoons located near the land where the sludge will be applied. The schemes for dewatered sludge concerned land application and landfill methods of ultimate disposal. The land application scheme proposed to pump the as-produced liquid sludge from Deer and Nut Islands plants to sites located on mainland where a rail-head and a filtration building would be constructed. When dewatered to 22% solids content, the sludge would be loaded into railroad cars and transported to the land application sites for storage and disposal. In the landfill scheme, basically the same sequence of sludge transportation was contemplated, except that the railroads cars would deliver the sludge to a sanitary landfill rather than to croplands. H&E did not investigate or select specific

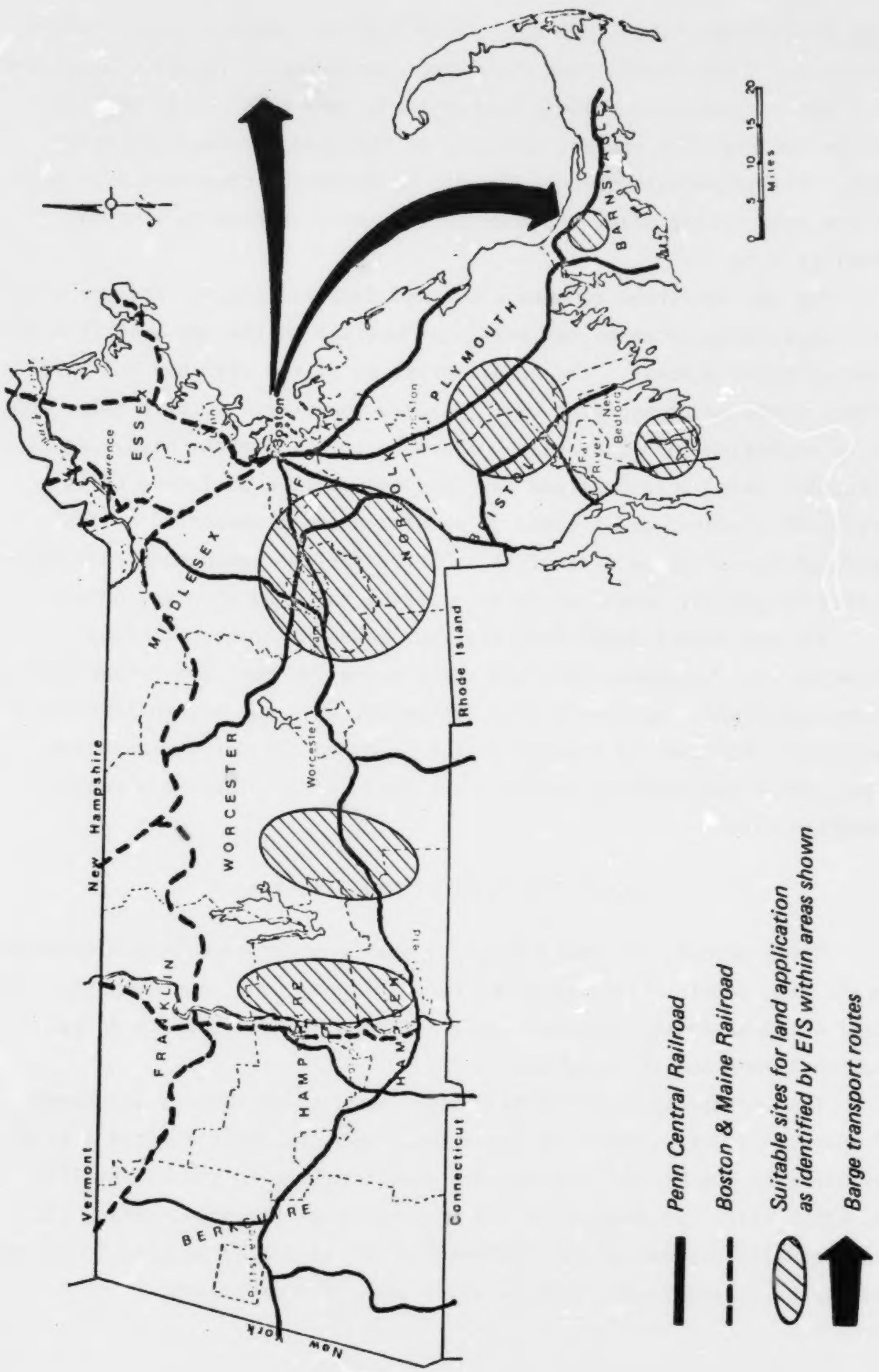

Vermont
New Hampshire
New York
Connecticut
Rhode Island
BERKSHIRE
FRANKLIN
HAMPSHIRE
HAMPDEN
WORCESTER
MIDDLESEX
ESSEX
NORFOLK
PLYMOUTH
BRISTOL
BARNSTABLE
Boston
Worcester
Lawrence
Fall River
New Bedford
Brockton
Pittsfield
Miles
0
5
10
15
20
Penn Central Railroad
Boston & Maine Railroad
Suitable sites for land application as identified by EIS within areas shown
Barge transport routes

Figure 2.2-4 Major Transportation Corridors

land application sites, but only identified the general zones appropriate for land disposal and determined approximate transport distances.

The incineration schemes contemplated some eight variations of sludge incineration process, but all of them had a common transport mode. The incinerated sludge ash was to be stored temporarily on site at the Deer Island plant and then periodically trucked to a remote landfill site.

The wet oxidation schemes concerned four variations, and the mode of sludge transportation was basically similar to the one described for land disposal schemes. The sludge produced at the Deer and Nut Islands plants would be transported via pipeline, some three to five miles long, to an oxidation and filtration building site. There the sludge could be directly loaded into railroad cars and transported as liquid to land application sites, or it could be dewatered and transported to land applications sites or a landfill. The land sites again were only identified by general zones, as in the case of the land disposal option.

The H&E report identified all four modes of transportation; selected the pipelines, rail and truck modes for cost comparison purposes and finally used only one alternative when the alternatives were selected. The mode of transportation selected for the incineration alternative was trucking ash from the Deer Island plant to a remote landfill site.

Draft EIS Transportation-Trains

Three methods of sludge disposal were contemplated in EcolSciences' Draft EIS, namely: incineration, ocean disposal and land disposal. The land disposal option involved sludge disposal by application on agricultural land and in landfill.

The incineration alternative considered three options for sludge disposal: (1) transport the incinerated ash, in containerized trailers, by barge to the Mystic Terminal and then truck it to the Plainville landfill site; (2) dispose of ash on-site in an enclosed, sealed fill area and (3) dispose of the incinerated ash at sea by barging it to the Murray-Wilkinson Basin, some 70 miles east of Deer Island.

The ocean disposal option proposed to transport the dewatered sludge by barge to the Murray-Wilkinson Basin.

The land disposal options proposed to use the dewatered sludge for agricultural purposes or dispose of it in the landfill. All of the options considered transporting the dewatered sludge, in containerized trailers, by barge to the Mystic Terminal and then trucking it to the land disposal sites or to the landfill site.

The Draft EIS identified all four modes of transportation, selected only the barging and trucking modes for cost comparison purposes and finally used the two selected modes for the recommended alternative. The mode of transportation selected for the incineration alternative was barging and trucking containerized ash to landfill disposal site.

2.3 Combustion Alternatives

2.3.1 Incineration

Description of Process

Incineration is essentially a volume reduction process in which the volatile matter in the sludge solids is combusted, with auxiliary fuel if necessary, to evaporate the water content of the sludge and reduce the residual solids to a pathogen-free ash. (The incineration of sewage sludge is described in detail in H&E's 1973 report and the Draft EIS.)

In the municipal wastewater treatment field, incineration is most commonly accomplished in multiple-hearth furnaces, although fluidized-bed furnaces are also in use in fewer numbers. Although the economics of fluidized-bed incineration appear to be comparable to multiple-hearth incineration (Jones et al. 1976; Camp, Dresser and McKee 1976), this study concentrates on multiple-hearth incineration because of its wide use nationally and its status as the recommended technology for the MDC sludge management plan.

The multiple-hearth incinerator consists of a cylindrical refractory-lined steel shell divided into a series of 6 to 12 hearths. Sludge cake commonly enters the top hearth (unless it is being used as an afterburner section) and passes down from hearth to hearth through drop holes. The sludge is mixed and spread across each hearth by rabble arms rotating on a central shaft.

Multiple-hearth incinerators are characterized by a temperature profile that ranges from approximately 800°F in the top hearth (when not used as an afterburner), 1,400 to 1,700°F maximum temperature in middle hearths and 500 to 600°F in the last hearth. Thus, the furnace is generally divided into three zones, beginning with sludge drying on upper hearths, sludge combustion on middle hearths and ash cooling on lower hearths. Afterburner sections for destruction of odors and hydrocarbon emissions can be added as external combustion chambers or by modifying of the uppermost hearth. Afterburner temperatures are typically 1,400 to 1,500°F.

Some or all hearth temperatures are monitored and controlled (manually or automatically) by adjusting combustion air or auxiliary fuel additions. The control of excess air (quantity of air added in excess of that theoretically required to burn all combustible matter) and the residence time of the sludge cake in the furnace are critical operational parameters.

The major inputs to the incineration process are "dewatered" sludge cake, combustion air and auxiliary fuel if needed. Because the economic success of the incineration process is so highly dependent on the characteristics of the dewatered sludge cake, it is necessary to consider the factors controlling those characteristics.

The dewatered sludge cake consists of noncombustible solids, combustible solids and water at 60 to 85% of the total cake weight. The amount of combustible solids is determined by the type of sludge (primary or secondary) and the extent to which the combustible solids have been reduced by prior sludge treatment (anaerobic or aerobic digestion). The heat value of the combustible matter (Btu/lb) is also variable. The noncombustible solids originate as the inert fraction of the primary or secondary sludge solids collected by the wastewater treatment processes or added during chemical treatment (for example, lime). The water fraction in the cake is dependent on the amount of water removed during the dewatering step preceding incineration.

For a given sludge, such as digested primary sludge in the Phase I MDC sludge management plan, the performance of the sludge conditioning and dewatering process will have a significant impact on auxiliary fuel requirements. In general, a drier sludge cake results in reduced auxiliary fuel use in the incinerator. However, the selection of conditioning and dewatering method must not be done on the basis of potential cake dryness alone. Dewatering processes must be compared on the basis of total operating costs, including amortization, power, chemicals, manpower and side-stream treatment, balanced against incinerator operating cost savings.

Potential conditioning and dewatering processes are described in H&E's 1973 report and the Draft EIS. Conditioning normally consists of either chemical conditioning or heat treatment. Dewatering equipment choices include vacuum filtration, filter presses (plate and frame or belt) and centrifuges. The reasons for selecting specific conditioning and dewatering processes for use with incineration alternatives in previous Boston sludge studies and this study are reviewed later. It is important to note, however, that the dryness of the sludge cake derived from these various dewatering processes, typically expressed as percent solids in the cake, must be assumed from prior experience in other cities when there are no existing dewatering facilities or test data at the plant being considered. A few percent difference in the actual percent solids in the sludge cake can result in significant differences in auxiliary fuel requirements.

Thus, for preliminary engineering of sludge incineration alternatives, it is often necessary to estimate values for sludge quantity, combustible content, heat value and cake dryness in addition to furnace parameters, such as exhaust temperatures and excess air. The planner or decision-maker should be aware of the uncertainty of these estimates. Pilot studies, where possible, can reduce the uncertainty of factors such as sludge dewatering ability.

Review of Local Studies

Havens and Emerson Reports

In 1973, H&E developed eight incineration alternatives in their report to MDC titled A Plan for Sludge Management. The H&E alternatives were compared on the basis of projected 1995 primary and secondary sludge quantities at Deer and Nut Islands. Satellite plants, such as those later recommended by EMMA, were not considered.

The H&E incineration alternatives were designed to evaluate the cost-effectiveness of various sludge treatment processes ahead of incineration to arrive at an optimized incineration alternative to be compared with the best land application and wet oxidation alternatives. The incineration alternatives evaluated the following processes with respect to their inclusion in an incineration process train:

- digested sludge vs. raw sludge
- heat treatment vs. chemical conditioning

- centrifugation vs. vacuum filtration
- fluidized-bed vs. multiple-hearth incineration

Sludge dewatering by filter presses was not evaluated, probably because the use of filter presses in municipal sludge treatment had not yet received much attention in this country by 1973. Also, all H&E incineration alternatives assumed consolidation of incineration facilities at Deer Island after an economic comparison of separate sludge incineration at Deer and Nut Islands showed separate facilities to be more expensive.

The 1973 report by H&E concluded that digestion of sludge, either anaerobic or aerobic, prior to incineration was not cost-effective. Anaerobic digestion was eliminated because of the high capital cost for expansion of existing digestion capacity to meet 1995 sludge quantities. Also, total system fuel and manpower costs were found to be greater when anaerobic digestion was included prior to incineration. Although the anaerobic digesters could possibly generate enough gas to provide the required digester heating, it is unclear whether the higher fuel costs were associated with auxiliary fuel requirements for the incinerators operating on a sludge feed containing a reduced amount of combustible matter or with digester heating. Although aerobic digestion was eliminated because of high operating costs (mostly electrical power and manpower), the annual fuel costs were the same as for incineration of raw sludge, indicating that additional auxiliary fuel for incineration of aerobically digested sludge was not anticipated.

Heat treatment for sludge conditioning was found to have higher capital and operating costs than chemical conditioning. Capital costs were greater because of the need for high temperature and pressure facilities. Operating costs were higher for fuel requirements and the impact on the main plant of recycling a high biochemical oxygen demand (BOD) filtrate created by dissolved organic matter during heating.

Compared to vacuum filters, centrifuges were found to have lower capital cost, but were eliminated because of higher total annual costs resulting from higher maintenance, chemical and power costs. Also, centrifuges were anticipated to have poorer solids capture characteristics resulting in higher percent solids return to the main plant via centrate recycle.

With respect to assumed values for cake dryness produced by vacuum filters, on page 90 of the H&E 1973 report, a solid concentration of approximately 20 to 30% was projected for the incineration alternative, and on page 81 a value of 22% solids in the filter cake (presumably mixed primary and secondary sludge) was assumed for the land application of dewatered sludge cake. In the October 1974 Environmental Assessment Statement for a Plan for Sludge Management by H&E, Appendix J presented 26% solids for Phase I digested primary sludge filter cake. Also appended to the 1974 EAS was a letter dated December 27, 1974 from H&E to Mr. Martin Weiss of the MDC using 25% solids in a cost comparison of incineration versus heat drying for fertilizer production from Phase I primary sludge.

The 1973 H&E report eliminated fluidized-bed incineration on the basis of higher fuel and electrical power costs, although multiple-hearth incinerators were found to have slightly greater capital cost. The higher fuel costs for fluidized-bed incinerators result because the entire furnace is maintained at approximately 1,400°F, whereas a multiple-hearth furnace without afterburners produces exhaust gas temperatures about 800°F after cake drying in upper hearths. However, if afterburners are required to raise multiple-hearth furnace exhaust temperatures to 1,400°F for odor and hydrocarbon emission control, the fuel advantages of multiple-hearth incinerators may be reduced or eliminated (Jones et al. 1976).

After making the process choices described above, the H&E 1973 report recommended an incineration alternative consisting of flotation thickening of waste-activated sludge,* mixing with unthickened primary sludge and storage in abandoned digesters at both Deer and Nut Islands. Nut Island sludge would be pumped via submerged pipeline to storage in abandoned digesters at Deer Island. The combined Deer and Nut Islands sludge would be chemically conditioned and then dewatered on vacuum filters before incineration in six (plus one standby) multiple-hearth incinerators on Deer Island.

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*Flotation thickening of waste-activated sludge is a process that introduces air at high pressure to the liquid stream. The air facilitates flotation of solids to the surface where they are skimmed off.

The 1973 H&E report indicates that, at 1995 conditions of mixed raw, dewatered primary and secondary sludge with filter cake at 26% solids and 69% of solids being combustible, the incineration process operating with 50% excess air will be autogenous at steady-state conditions. Only 0.11 gallons of fuel per hour per furnace would be required at a furnace exhaust gas temperature of 1,136°F. This minimum fuel requirement may have been only that required for pilot burners. As used here, this furnace exhaust temperature is essentially the break-even point between autogenous combustion and combustion requiring auxiliary fuel for the sludge feed conditions as stated, that is, to achieve higher exhaust temperatures, auxiliary fuel would be required.

As mentioned previously, a furnace exhaust temperature of approximately 800°F is typical without afterburners, and 1,400°F is typical with afterburners. Operation at the maximum autogenous combustion exhaust temperature (without afterburners) would maximize potential waste heat recovery. However, odor could be increased by raising sludge cake temperatures on upper hearths.

Waste gases (at 1,136°F for 1995 conditions) from the incinerators would be passed through waste heat boilers with a boiler exhaust temperature of 250°F. The heat recovered from this 886°F temperature drop was estimated to produce 2.52×10^9 Btu per day of steam. Using steam turbine generators, approximately 10,000 Kw of electrical power could be produced based on an assumed steam to electricity efficiency of 38% and a power utilization factor of 87%.

Boiler exhaust gases would be passed through a venturi scrubber before discharge. Afterburners were provided for use if necessary. It was stated in the EAS that auxiliary fuel requirements would increase to 30 gallons of oil per hour per furnace if afterburners at 1,300°F were required.

The recommended incineration alternative in the 1973 H&E report included $1,642,400 (1973 dollars) for construction of on-site ash lagoons for temporary ash storage before ultimate disposal at off-site landfill sites, resulting in a total project capital cost of $46,202,000 (1973) as shown in Table 2.3-1. The 1974 EAS has an ash disposal facility capital cost of $8,200,000 for construction of a permanent on-site ash landfill behind 3,400 linear feet of cofferdam with a plastic liner to prevent leachate release. The total capital cost presented in the 1974 EAS for the primary and secondary sludge incineration plan facilities was $53,040,100 (1973 dollars). A letter dated February 14, 1974 from H&E to Mr. Martin Weiss of the MDC, appended to the 1974 EAS, stated that the permanent on-site landfill option was considered after MDC staff indicated interest in that option, and the letter further stated that a final decision on the ash disposal method had not been made at that time.

The detailed cost-effectiveness analysis presented in the 1973 H&E report was prepared on the basis of projected combined 1995 primary and secondary sludge quantities and composition. The 1985 Phase I facilities were described in the 1973 H&E report after the recommended primary and secondary sludge incineration plan was developed. The Phase I interim incineration facilities were essentially initial pieces of the projected 1995 facilities. Various Phase I staging alternatives other than incineration were not considered, presumably because the results of the primary and secondary sludge alternative analysis could be considered applicable to primary sludge alone and because a long delay in the implementation of secondary treatment facilities was not anticipated.

The H&E 1973 cost estimate for Phase I facilities is presented in Table 2.3-2. The Phase I facilities include 4,500 square feet of vacuum filter area, three (of the ultimate seven) 25 ft-9 in. diameter nine-hearth incinerators with waste-heat boilers and afterburners and one 3,400 Kw turbine generator. Anaerobic digestion of primary sludge was to continue for the useful life of existing digester equipment, which apparently was expected to be at least through the year 1985. Existing gravity thickeners at Deer Island would continue in service.

TABLE 2.3-1

CAPITAL COSTS
RECOMMENDED PROJECT PLAN (1995)
(Primary and Secondary Sludge)

Item	Costs
Nut Island	
Flotation Thickeners	$ 1,812,400
Sludge Pump Station and Pipelines to Deer Island	4,852,800
Miscellaneous Facilities*	442,000
Total for Nut Island	$ 7,107,200
Deer Island	
Electrification of Raw Sewage Pumps**	$ 1,920,000
Flotation Thickeners	3,584,700
Vacuum Filters and Incinerators	24,502,800
Power Generation Station	5,576,400
Miscellaneous Facilities†	1,869,000
Ash Lagoons and Landfill	1,642,400
Total for Deer Island	$39,095,300
Total Project Cost (Rounded)	$46,202,000††

*Includes service water, tunnels and yard work.

**After allowance for $180,000 salvage value for nine engines.

†Includes service water facilities, gravity thickener and storage tank odor control, tunnels and yard work.

††1973 dollars, ENR cost index: 1,896.

Source: H&E 1973.

The costs presented in Table 2.3-2 do not include money for construction of on-site ash lagoons nor, apparently, for a cofferdam. The H&E 1973 report states:

> The construction of ash lagoons will be deferred until a later date. During Phase I, incinerator ash would be pumped to the northern edge of the plant site to create the filled area required for addition of secondary treatment.

The nature of this filling method and potential environmental impact is not described in detail.

EPA Draft EIS

The 1976 Draft EIS prepared by EcolSciences for Region I of the U.S. EPA presented three Phase I incineration alternatives, digested primary sludge only, which were identical to the Phase I facilities recommended by H&E (1973) except for the ash disposal method and power generation facilities. In EPA's Alternative 1, incinerator ash (63 dry tons per day) would be barged 6.3 miles in containerized trailers from Deer Island to the Mystic terminal in Boston. The trailers would be hauled 30 miles by truck to the sanitary landfill at Plainville. In EPA's Alternative 2, incinerator ash would be used as on-site landfill on Deer Island behind a cellular cofferdam (1,800 linear feet) with a plastic liner to aid leachate control. In EPA's Alternative 3, ash would be barged 70 miles to sea and dumped.

Waste heat recovery with power generation was not included in the incineration alternatives considered in the Draft EIS because of uncertainty about feasibility. (The potential for waste heat recovery is discussed in a following section.)

Table 2.3-3 presents a summary of the capital and equivalent annual cost data for each of the incineration alternatives presented in the Draft EIS. A breakdown of the on-site incineration process costs is not provided in the Draft EIS. Page 153 of Volume II of the Draft EIS states that the 1973 cost data from H&E were used and scaled up to April 1975 dollars with a factor of 1.27 (ratio of EPA construction cost index

TABLE 2.3-2

CAPITAL COSTS
PHASE I

(Primary Sludge)

Item	Costs
Nut Island	
Sludge Pump Station and Pipelines to Deer Island	$ 4,852,800
Deer Island	
Electrification of Raw Sewage Pumps*	$ 1,920,000
Vacuum Filters and Incinerators	12,009,600
Power Generation Station	2,435,000
Miscellaneous Facilities**	798,500
Total for Deer Island	$17,253,100
Total Project Cost (Rounded)	$22,016,000†

*After allowance for $180,000 salvage value for nine engines.

**Includes service water facilities, gravity thickener odor control, tunnels, and yard work.

†1973 dollars ENR cost index 1896.

Source: H&E 1973.

TABLE 2.3-3

COST SUMMARY OF INCINERATION ALTERNATIVES PRESENTED IN THE DRAFT EIS

		Capital Cost*						
#	Alternative	On-site Processes	Ash Disposal Facilities	Total Capital	Amortized Capital Cost (20 yrs @ 6.125%)	Annual Operation and Maintenance Costs**	Total Annual Cost	Unit Cost ($/dry ton)†
1	Ash Off-Site Landfill	22,502,200	865,000	23,367,200	2,080,700	1,930,000	4,010,700	91.95
2	Ash On-Site Landfill	22,502,200	5,181,300	27,683,500	2,438,100	1,567,600	4,005,700	91.84
3	Ash Ocean Dumping	22,502,200	1,000,000	23,500,000	2,069,700	1,671,400	3,741,100	85.77

*All capital costs are April 1975 dollars, ENR cost index 2135

**O&M costs are based on the following unit costs

labor @ $6.84/hr
electricity @ $0.0275/Kwh
fuel @ $0.38/gal No. 2 oil
maintenance @ 2% of capital cost
lime @ $55/ton
Ferric chloride @ $135/ton

†Basis: 119.5 dry tons per day of digested primary sludge solids in 1985.

Source: Draft EIS

for Boston of 188.63 in July 1973 to 240.30 in April 1975). Region I EPA staff have confirmed that capital costs for incineration alternatives in the Draft EIS do not include electrification of raw sewage pumps at Deer Island and power generation facilities, which were included in the original H&E cost estimate of Phase I facilities (Table 2.3-2) (Shaugnessey 1977a). Electrification of raw sewage pumps at Deer Island has proceeded independently of sludge facility construction.

In the Draft EIS, the annual operation and maintenance costs for incinerators were calculated on the basis of autogenous combustion (without auxiliary fuel) under steady-state conditions. However, an average fuel allowance of 405 gallons per day of No. 2 oil was assumed for pilot fuel and start-up fuel. One furnace start-up requiring 4,000 gallons of fuel was assumed every 10 days. Thus, for 1985 conditions with two furnaces operating, each furnace is started once every 20 days. Although 24 hours per day, 7 days per week operation is assumed for two furnaces at 1985 sludge quantities, it is difficult to predict start-up frequency. One start-up every 10 days may be more or less conservative but it appears reasonable for preliminary planning; however, 4,000 gallons per start-up may be excessive. Other sources have indicated 400 to 600 gallons per start. A sludge management planning report prepared for the New York-New Jersey Interstate Sanitation Commission indicated approximately 400 gallons of No. 2 fuel oil is required to reach the operating temperature of a large multiple-hearth furnace (22- or 25-ft diameter) from 60°F (Camp, Dresser and McKee and Potter 1976). An incinerator manufacturer estimated start-up fuel requirements for a large multiple-hearth furnace, as above, could be as much as 600 gallons per start, depending on ambient air temperature and furnace temperatures at start (Allen 1977a). Frequent furnace start-ups increase furnace maintenance costs because of more frequent replacement of brick damaged by extreme temperature fluctuations.

The Draft EIS projected that, at 1985 average conditions of dewatered, digested primary sludge with a filter cake solids content of 30% and 50.5% combustible solids, the incineration process operating at 50% excess air will be autogenous at steady-state. The maximum furnace exhaust temperature under autogenous conditions in 1985 was reported to be 938°F. These calculations were made for the 1985 average daily sludge production rate excluding grit, scum and screenings. Autogenous combustion was indicated for average and peak daily sludge quantities in 1980 and 1985.

A summary of heat balance data taken from the 1976 Draft EIS is reprinted in Table 2.3-4. The original table in the Draft EIS cites the 1973 H&E report as the source of the information. However, these data do not appear in the 1973 report, but presumably were support data for the 1973 report. The heat balance data did appear, as shown in Table 2.3-4, in a February 14, 1975 letter (appended to the 1974 EAS) from H&E to Mr. Martin Weiss of the MDC. This chronology is important only in that the table in the February 14, 1975 letter is the first published item in which it is indicated that a 30% solids filter cake (70% moisture) could be achieved with mixed digested primary sludge from Deer and Nut Islands. The Draft EIS presents a summary of projected 1985 sludge characteristics in Table N-2, which is an exact reprint of Appendix J from the 1974 EAS except that, instead of 26% solids in the filter cake, 30% solids is substituted with the note: "Modified to be in accordance with projected heat balances."

In support of the assumed sludge dewatering characteristics, the Draft EIS presents a review of three existing municipal sewage sludge incinerators that were incinerating raw primary sludge. It was reported that vacuum filter cakes "averaging about" 30% solids were obtained at these plants. Any variability in the solids concentration was not reported. Note that digested sludges typically require greater quantities of conditioning chemicals than raw sludges because of higher alkalinity of digested sludges, thus producing filter cakes with greater quantities of noncombustible precipitate in the solid fraction.

The Draft EIS described alternative dewatering devices and concluded that, in terms of capital, labor and energy inputs per ton, vacuum filters and filter presses were similar, noting that chemical requirements for filter presses were greater. The Draft EIS concluded that filter presses could be substituted for vacuum filters during

TABLE 2.3-4

HEAT BALANCE AT EQUILIBRIUM CONDITIONS

Variable	1980 Average	1980 Peak	1985 Average	1985 Peak
Wet feed, lb/hr (each unit)	31,600	19,400	17,700	21,700
Number of incinerators in operation	1	2	2	2
Moisture content of feed, %	70	70	70	70
Base temperature of feed, °F	60	60	60	60
Base temperature of air, °F	60	60	60	60
Moisture in air, lb/lb	0.01	0.01	0.01	0.01
Temperature of flue gas at exit, °F	911	912	938	995
Temperature of ash at exit, °F	600	600	600	600
Excess air, % of theoretical air	50	50	50	50
Total air required for combustion, lb/hr	54,567	34,195	32,022	40,426
Cooling air lost to atmosphere, %	50	50	50	50
Radiation loss, Btu/ft^2/hr	130	130	130	130
Total heat in flue gases above 60°F, Btu/hr (includes vapor)	48,574	30,047	28,048	35,802
Fuel oil required (143,000 Btu/gal), gal/hr	0	0	0	0

*From calculations by H&E 1973.

Source: EcolSciences 1976.

detailed design, thus implying that 30% solids are assumed for vacuum filter cake, and the potential advantages of using filter presses producing a drier cake (approximately 40% solids) would be evaluated in detailed design after pilot testing.

The EMMA Study

With respect to sludge processing, the EMMA study refers to the 1973 H&E plan for management of sludge generated at Deer and Nut Islands. The EMMA study presents a total Phase I plus Phase II project cost of $53,667,000 (ENR 2200) for incineration of primary and secondary sludge at Deer Island. (EMMA presents a Phase I sludge facilities cost of $25,573,000 (ENR 2200). The project cost of $53,667,000 (ENR 2200) was apparently obtained by scaling up the original H&E estimated project cost of $46,202,000 (ENR 1896) for projected 1995 sludge quantities at Deer and Nut Islands. The original H&E total project cost for sludge facilities was apparently scaled up to ENR cost index 2200 without adjustment for differing sludge quantities projected in the two studies nor inclusion of the extra capital cost for on-site landfill of ash behind a cellular cofferdam.

Any necessary modifications to the recommended H&E 1995 plan, resulting from reduced sludge quantities at Nut Island after satellite treatment plants are implemented, were not discussed in the EMMA study. Furthermore, the EMMA study assumed incineration of sludge produced at all satellite plants greater than 10 million gallons per day (mgd) in capacity. This assumption was based on an analogy with the 1973 H&E findings without detailed consideration of the differing quantities and composition of sludge generated at the proposed advanced wastewater treatment (AWT) plants. The major sludge disposal options considered in detail in the EMMA study for the satellite plants dealt with the question of where to locate separate or consolidated incineration facilities for the proposed AWT plants.

Review of Other Studies

The operating experience of sludge incinerators in this country can be divided roughly into two time periods. The first period corresponds to the "old" design of multiple-hearth sludge incinerators and associated dewatering facilities that developed during the time of cheap energy. These "first-generation" incinerators generally used higher excess air rates (75% or greater), fixed-speed induced draft (ID) fans and rather simple temperature control instrumentation. Perhaps more significant than the incinerator design itself were the limitations of dewatering equipment, that is, vacuum filters capable of producing filter cakes with 25% to 30% solids, at most. Cakes with less than 20% solids were not uncommon for secondary sludge. Incinerators such as these generally required auxiliary fuel. Typically, approximately 50 gallons of No. 2 oil (6.75 million Btu) per ton dry sludge solids was required for a filter cake with 20 to 25% solids (Jones et al. 1976).

The second period of incinerator technology is now being entered with more advanced designs of "second-generation" incineration facilities, including improved dewatering capabilities, sophisticated control systems for incinerators and, often, waste heat recovery. The incineration facilities proposed for Deer Island fall into the second-generation category. Proposed incinerators at Deer Island include variable speed ID fans operated by a control loop from an oxygen sensor in the stack, variable sludge feed and rabble arm speed and low excess air rates for all sludge feed rates. Although the original 1973 plan proposed vacuum filters for dewatering, the recent Draft EIS suggested that filter presses capable of producing a drier cake also be investigated. These second-generation incinerators are proposed to be autothermal (requiring no auxiliary fuel during normal operation).

In July 1977, EPA completed a listing of sewage sludge incinerators in all its regions (Rhett 1977). It was indicated that data on greater than 90% of existing incinerators were obtained and that data on approximately 50% of proposed facilities were obtained. The summary of this survey is presented below (Rhett 1977).

- Sludge incinerators are operating or are planned in 36 states and Puerto Rico.
- Of the 135 existing incinerators in operation, 9 use both gas and oil, 61 use gas, 57 use oil, 2 are electrically powered and 6 have alternate fuel arrangements such as solid waste utilization or reliance on self-sustaining operation.
- Of the 92 future incinerators being planned, 14 will use both oil and gas, 16 will use gas, 38 will use oil, 10 will be electric and 14 will have alternate fuel arrangements.
- There are at least 25 existing incinerators not in operation.
- The present annual fuel consumption of the incinerators is 4,696 million cubic feet of gas, 15,358 thousand gallons of oil and 2,458 thousand Kw-hr of electricity.
- The known additional future fuel consumption for incinerators is projected as 1,368 million cubic feet of gas, 24,684 thousand gallons of oil and 2,612 thousand Kwh of electricity on an annual basis.

Of the 25 existing incinerators indicated as no longer operating, 14 existing incinerators constructed since 1970 in Connecticut are not operating. The EPA survey does not describe the circumstances of incinerator shutdown. However, Region I staff in the wastewater treatment facility operation and maintenance section indicated that the high cost of fuel is the major reason for shutdown of sludge incinerators in Region I, and that fuel use typically becomes excessive for incinerators operated at less than full capacity (Brill 1977). The latter problem supposedly is corrected by more sophisticated control systems in second-generation incinerators, although over-design must still be avoided.

Operating experience with more advanced incinerators is extremely limited, but it is estimated that approximately 25 energy-saving sludge incinerators will be operating by 1979 (Jacknow 1977). Available information indicates that, nationwide, six or seven energy-saving incinerators have been constructed to date. Until more experience is gained with improved dewatering and incineration technology, it must be recognized that proposals for advanced sludge incineration facilities are not without elements of uncertainty. ERT has contacted operating personnel at two recently constructed advanced incineration facilities to determine if design specifications for operation without auxiliary fuel are being met.

The first plant contacted was the Annapolis, Maryland wastewater treatment plant (Arundel County). Incinerator facilities were built in 1975 and consist of the following unit processes:

- one heat treatment unit for sludge conditioning (gas fired);
- two centrifuges for sludge dewatering and
- one multiple-hearth furnace (auxiliary gas fired).

There are no waste heat recovery boilers, and the plant processes mixed primary and secondary sludge. The centrifuges produce a dewatered sludge with 26 to 30% solids, but problems with the centrifuges have prevented any sustained period of incineration (Kontegias 1977). The longest continuous period of incineration has been approximately one week, and the incinerator has not yet operated without auxiliary gas (Kontegias 1977).

The Louisville (Kentucky) Metropolitan Sewage District operates incineration facilities that were designed for autogenous operation with mixed primary and pure oxygen secondary sludge. The incineration facilities, which began operation in 1976, consist of the following:

- heat treatment for sludge conditioning (oil fired);
- vacuum filters for dewatering and
- multiple-hearth furnaces (three 22-ft diam. x 8 hearths, each with an afterburner and waste heat boiler).

Normally, two furnaces are operated 24 hours per day, 7 days per week. The furnaces and afterburners are fired by No. 2 fuel oil. Steam from the waste heat boilers is used in the winter to heat buildings and used as process steam throughout the year.

The vacuum filters dewater heat-treated sludge to approximately 40% solids. However, solids captured in the filters have been only 60% efficient, resulting in a high solids return load to the plant.

The furnaces at Louisville have operated autogenously; however, a higher-than-design heat value of sludge solids has occasionally resulted in excessive temperatures (about 2,000°F) in the furnaces (Mazzoli 1977). To adjust temperatures, manual measures such as opening furnace doors and adjusting rabble arm speed are required. Each operating furnace is fed 4.7 to 5.2 tons of sludge per hour (design rate is 9 tons per hour), but at loadings greater than 6 tons per hour, temperatures are uncontrollable. The control systems are highly automated, but furnaces are normally opeated manually, that is, manual control of excess air and rabble arm speed. A stack gas oxygen sensor has performed erratically and is no longer used for damper control.

Although the furnace can operate without auxiliary fuel after start-up, the heat treatment units and afterburners require auxiliary fuel oil, the latter each requiring 60 to 120 gallons of oil per hour. Afterburner exhaust gases are 1,200 to 1,400°F, and boiler exhaust temperatures are approximately 500°F. There has been no significant boiler corrosion. The waste heat boilers (rated capacity 28,000 lbs steam/hour) on each furnace are over-designed for present duty because only one boiler per two furnaces is now used to produce 15,000 to 18,000 lbs/hour (Mazzoli 1977).

Although these plants are only two of the six or seven advanced design incineration facilities now reportedly operating in this country, the experience at these advanced plants indicates that some problems with sludge incineration technology still remain. It appears that the performance of dewatering equipment continues to be crucial and that temperature control of autogenous sludge combustion is a complex problem. Conversations with an equipment manufacturer consultant have indicated that of the four or five remaining advanced design incinerators, two units are reported to be operating autogenously in Green Bay, Wisconsin (designed to handle 11,000 lbs/hour of sludge). Another incinerator in Erie, Pennsylvania is not operating autogenously, but is recovering heat. Two incinerators, one in Granite City, Illinois and one at Western Branch in Prince Georges County, Maryland, are reported idle because of over-design and subsequent loss of operational cost effectiveness.

The two plants that have been shut down seem to indicate that the so-called advanced design concepts do not render incinerators insensitive to the problems of over-design, a problem that has plagued the older type of incinerator.

Energy Considerations

Summary of Design Assumptions for Autogenous Combustion

As described previously, the incineration alternatives evaluated in both the 1973 H&E report and the Draft EIS were assumed to require no auxiliary fuel under steady-state conditions without afterburners operating. The maximum obtainable furnace exhaust temperatures under autogenous conditions for various design years were determined by computerized heat-balance calculations. The assumed input variables to these heat-balance calculations are shown in Table 2.3-4.

The major parameters influencing projected incinerator performance with respect to energy balance (and the values assumed in the Draft EIS for 1985 Phase I sludge for these parameters) are summarized below:

- solids content of sludge feed (30% solids by weight),
- heat value of sludge feed (5595 Btu per lb dry solids),
- amount of excess air above theoretical requirements (50%) and
- furnace exhaust temperature (938°F).

Also, the inclusion of waste heat recovery facilities will influence overall economics of operation and should be evaluated as an option.

Process Uncertainties

To evaluate the sensitivity of projected auxiliary fuel requirements to changes in the above parameters, a series of heat balances were calculated for multiple-hearth incinerators using a range of values for these parameters. The heat-balance calculations for the various cases were performed using a computer program developed by Envirotech Corporation for sizing and estimating costs of multiple-hearth incineration equipment. The Envirotech Corporation computer program is proprietary and has been verified with data from operating installations.

The variability that can occur in each of the important heat-balance parameters previously identified is discussed below.

- Solids Content of Sludge Feed

  The solids content of the sludge feed is a measure of the performance of the sludge conditioning and dewatering equipment. The dryness of the sludge cake can, of course, vary with the type of equipment selected (that is, vacuum filters versus filter presses). However, the dryness of the filter cake produced by a particular type of equipment also varies in different applications because of site-specific sludge characteristics. Thus, the assumed filter cake percent solids presented in previous local studies ranged from approximately 25 to 30% for Phase I digested primary sludge dewatered with vacuum filters. The operator has some control over cake dryness by varying the filter yield (lbs dry solid per hour per square foot of filter area) depending on equipment availability. By accepting lower yields, which requires greater filter capacity, a drier cake can be produced.

  For the purposes of this study, heat balances were performed using 30% solids in the vacuum filter cake to represent the design case described by sludge composition data in Table N-2 of the Draft EIS. Heat balances were also performed using 26% solids to represent poorer, but not unreasonable, performance by vacuum filters, as described by sludge composition data in Table J of the 1974 EAS.

To represent the significantly drier filter cake that can be achieved with pressure filtration, a value of 40% solids was used in some heat balances. It was assumed that 40% solids could be obtainted using a filter press following chemical conditioning.

All these assumed filter cake solids concentrations were selected based on past experience in other cities because very little data are available on dewatering of sludge at Deer and Nut Islands, where sludge is now discharged to the ocean. The data that are available suggest that solids concentrations of approximately 26 to 40% can be obtained using currently available technology, at least for thickened, raw primary sludge at Deer Island. Limited bench scale dewatering tests performed by Envirotech Corporation at Deer Island in January 1977 found, in two samples, that thickened raw primary sludge could be vacuum filtered (with a standard filter leaf test) to 26.7% solids and that the vacuum filter cakes could be further dewatered to 39.1% solids and 40.6% solids in a bench scale pressure filter section (Donnelly 1977). Chemical conditioning was used in these tests with $FeCl_3$ at 1.5% and $Ca(OH)_2$ at 6.0% by weight of dry sludge solids.

On two comparable tests of digested primary sludge using $FeCl_3$ at 3.9% and $Ca(OH)_2$ at 11.7% by weight, it was found to be impossible to get a vacuum filter cake to form (Donnelly 1977). At the time, some digester upset was believed to have been the cause of the poor filter tests; however, Deer Island staff have indicated that the digesters were performing normally that winter. The problem is unclear, but the need for pre-design pilot testing of alternative dewatering techniques, as recommended in the Draft EIS, is apparent.

- Heat Value of Sludge Feed

The heat value is derived from the volatile (combustible) fraction of the sludge solids.

The heat value of the sludge feed (Btu per lb total dry solids) is variable from day to day or even hour to hour at a single plant. The heat value of raw sludge is greater than that of digested sludge because digestion consumes a portion of the volatile solids.

H&E determined the heat value of the volatile (combustible) fraction of the dry sludge solids in two 3-day composite samples at each plant in November 1972, as reported in Table I-4 of the 1973 report. For digested sludge, the heat value of the volatile solid fraction ranged from a maximum of 13,400 Btu/lb volatile solids to a minimum of 9,900 Btu per lb volatile solids. For raw sludge, the range in heated values was 12,300 Btu per lb volatile solids to 10,600 Btu per lb volatile solids. The sludge samples apparently did not include scum or screenings.

The heat-balance calculations originally performed by H&E and reported in Table 2.3-4 of this report used a heat value of 11,080 Btu/lb volatile solids in the 1985 average day sludge composition. Using a volatile solids concentration of 50.5% of the total dry solids after digestion, a heat value of 5,595 Btu/lb total dry solids was used for the 1985 Phase I digested primary sludge heat-balance calculations by H&E. This heat value and, thus, any higher values were found to be sufficient for autogenous combustion under the conditions indicated for the 1985 design case shown in Table 2.3-4.

To evaluate the impact on auxiliary fuel requirements of lower heat values, ERT has performed some heat balances using 9,900 Btu per lb volatile solids or equivalently 5,000 Btu per lb total dry solids.

- Amount of Excess Air

  The amount of excess air, which is a critical variable that affects furnace energy requirements, is the amount of air above theoretical requirements for complete combustion. Design excess air for incineration processes is normally at least 75% on volatiles plus 15% excess air on auxiliary fuel (Jones et al. 1976). As noted in the Draft EIS, the amount of excess air in existing incinerators is commonly fixed at design capacity requirements resulting in increased amounts of excess air in underloaded furnaces. The proposed use of a variable-speed ID fan controlled by oxygen sensors in the stack is not now included in standard sludge incinerator design and, as such, represents new technology. However, the successful operation of an exhaust gas oxygen sensor to control the induced air fan damper at San Mateo, CA has been reported.

  Assuming that excess air can be maintained at 50% under all loading conditions, 50% excess air would be below the 75% excess air level normally used in design and could lead to problems with incomplete combustion (Allen 1977b). Whether or not complete combustion can be attained at excess air levels of 50% will be verified during operation. As stated in the Draft EIS, excess air amounts may rise intermittently to 75% even in the proposed incinerators. Therefore, heat balances were performed using 50% excess air as the design case. Excess air values of approximately 75% were used in some steady-state heat-balance calculations to provide comparative fuel requirements under more typical excess air conditions.

- Furnace Exhaust Temperature

  In the heat balances performed by H&E as appended to the 1974 EAS, maximum furnace exhaust temperatures under autogenous conditions were calculated for various design years. These temperatures were shown to increase each year from 938°F in 1985 to 1,067°F in 1995 as the volatile solids content increased because of phase-out of digesters and addition of secondary sludge solids. For the 1985 average day conditions for the heat balances presented herein, a minimum furnace exhaust temperature of 938°F was assumed to compare auxiliary fuel requirements on a common basis. If insufficient heat were provided by the sludge alone, auxiliary fuel would be added as necessary to reach 938°F. To the extent that lower exhaust temperatures would be tolerated, fuel requirements could be reduced in practice.

To establish fuel requirements when afterburners are required for control of odors and hydrocarbon emissions, an afterburner exhaust temperature of 1,400°F was assumed based on similar afterburner temperature requirements in air pollution control regulations in areas of New York and New Jersey (Camp, Dresser, McKee and Potter 1976).

- Waste Heat Recovery

Waste heat recovery and on-site power generation facilities were eliminated from the incineration alternatives considered in the Draft EIS. Although the incorporation of waste-heat recovery facilities with sewage sludge incinerators has not been done routinely in the past, it appears that such facilities will become more frequent as energy prices rise. Although use of waste-heat boilers on incinerators followed by turbine generators is not the most efficient method of burning fuel oil to produce electricity, it is possible to recover some of the energy that would otherwise be wasted.

The waste-heat boilers suggested originally by H&E were to be operated with gas exhaust temperatures of 250°F. As pointed out in the Draft EIS, this temperature is too low and could result in corrosion problems from condensation of hydrochloric or sulfuric acid. For the purposes of this study, a boiler exhaust temperature of 450°F is used.

For 1985 conditions, waste-heat boilers would be used to produce steam by cooling furnace exhaust gases from 938°F to 450°F. If afterburners are used, the temperature drop would be 1,400°F to 450°F.

Steam was assumed to be produced at 825°F, 600 psig and condensed at 2 in. Hg absolute. Assuming a turbine generator efficiency of 75%, these steam conditions would result in a steam to electrical power efficiency of approximately 28%.

Evaluation of Supplemental Fuel Requirements

The variables discussed above were grouped into a number of cases of feasible incinerator operating conditions, and heat balances were calculated for 1985 conditions. A summary of the incineration cases considered, showing design variables and resulting auxiliary fuel requirements, is presented in Table 2.3-5.

In Cases I_1, I_2, I_3, I_5, I_7 and I_8, the excess air input values were 50% and in Cases I_4 and I_6 the excess air input value was 75%. In Cases I_1 and I_8, the significantly higher excess air values result because cooling is required to hold exhaust temperatures at 938°F, that is, the maximum exhaust temperature under autogenous conditions is greater than 938°F for the conditions stated. In all remaining cases, the discrepancies between excess air input values and the final excess air values are due to computer closure error (Allen 1977a).

The furnace sizes and auxiliary fuel requirements shown in Table 2.3-5 are based on the indicated 1985 maximum day sludge feed rate with two furnaces operating 24 hours per day, 7 days per week. For 1985 average daily sludge feed rates, the furnaces would be operating at slightly underloaded conditions (approximately 82% of full capacity). As discussed in detail in the Draft EIS, for underloaded operation auxiliary fuel requirements would normally increase if combustion air rates were fixed, that is, excess air quantities would be increased. The proposed incineration facilities at Deer Island would contain variable combustion air control systems to maintain a constant percentage of excess air. Proper functioning of the proposed combustion air control system should do much to offset any increase in auxiliary

TABLE 2.3-5

SUMMARY OF INCINERATION DESIGN VARIABLES AND RESULTING AUXILLARY FUEL REQUIREMENTS

(1985 Conditions)

Variable†	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
lbs. dry sludge/day (total)								
average	255,000	255,000	255,000	255,000	255,000	255,000	255,000	469,000
maximum	312,000	312,000	312,000	312,000	312,000	312,000	312,000	574,000
% volatile solids	50.5	50.5	50.5	50.5	50.5	50.5	50.5	68.3
Btu/lb VSS	11,080	11,080	11,080	11,080	9900	9900	11,080	11,080
% solids in cake	40	30	26	30	30	26	30	26
Base temp of sludge, °F	60	60	60	60	60	60	60	60
Base temp of air, °F	60	60	60	60	60	90	60	60
Moisture in air, lb H_2O/lb air	0.01	0.01	0.01	0.01	0.01	0.028	0.01	0.01
Excess air, % of theoretical air for volatile solids*	151	50	52	76	52	79	55	71
Exhaust gas temp. °F	938	938	938	938	938	938	1400	938
Boiler exhaust gas temp. °F	450	450	450	450	450	450	450	450
Ash temp. °F	600	600	600	600	600	600	600	600
Shaft air return %	50	50	50	50	50	50	50	0
No. of furnaces operating	2	2	2	2	2	2	2	2
Furnace size (diam-hearths)	22'-3"-9H	22'-3"-9H	22'-3"-9H	22'-3"-9H	22'-3"-9H	22'-3"-9H	22'-3"-9H	25"-9"x12H
Auxiliary fuel (max. day)								
No. 2 oil gph/furnace	0	8	58	24	42	106	130	0
Btu/hr/furnace x 10^6 @ 143,000 Btu/gal	0	1.14	8.29	3.43	6.01	15.2	18.6	0

*In cases I_1, I_2, I_3, I_5, I_7 and I_8, excess air input values were 50%, and in Cases I_4 and I_6, excess air input value was 75%. In cases I_1 and I_8, the significantly higher excess air values resulted because cooling was required to hold exhaust temperature at 938°F. In all remaining cases, the discrepancies between excess air input values and the final excess air values are due to computer closure error.

†Cases I_1 - I_7 are for digested sludge, Case I_8 is for raw sludge.

fuel requirements due to operation of the furnaces at less than full capacity. Therefore, assuming excess air maintained at indicated levels, the fuel requirements on days of average sludge loading should be approximately 82% of the fuel requirements shown in Table 2.3-5.

- Case I_1 corresponds to incineration of anaerobically digested sludge that has been dewatered to 40% solids. At 40% solids in the filter cake, incineration is clearly autogenous at excess air rates up to approximatly 151% of theoretical requirements.
- Case I_2 is similar to the proposed incineration of anaerobically digested sludge dewatered to 30% solids with 50% excess air. In the heat-balance calculations done for this study, a fuel requirement of approximately eight gallons per hour per furnace is projected. This amount of auxiliary fuel is minimal compared to the other cases in which auxiliary fuel is required. Whereas the heat balances performed by H&E for a similar situation indicate autogenous combustion at an exhaust temperature of 938°F, the differences may be accountable to differing assumptions for radiation losses, ultimate analysis of sludge or heat capacity data. It is only important to note that 30% solids in the filter cake is roughly the dividing point between autogenous combustion and combustion requiring auxiliary fuel for the proposed Phase I incineration facilities.
- Case I_3 indicates how rapidly auxiliary fuel requirements increase when a wetter filter cake of 26% solids is produced, even if excess air is maintained at approximately 50%.
- Case I_4 indicates the increase in auxiliary fuel requirements if excess air is maintained at more normal levels of about 75% instead of 50%.
- Case I_5 demonstrates how a change in the heat value of the volatile solids in the sludge cake can influence fuel needs.
- Case I_6 represents a situation in which a number of factors contribute to increased auxiliary fuel needs, that is, lower heat value, wetter cake and increased excess air. Because

the heat value was actually measured by H&E, the excess air at 79% is comparable to normal levels in existing incinerators, and a filter cake with 26% solids is not uncommon for vacuum filters. Case I_6 represents a possible outcome that should be considered in a planning study.

The base air temperature of 90°F does not significantly affect fuel requirements compared to 60°F. For heat balances not shown, ambient air temperatures of 35°F and 90°F result in changes in fuel requirements of approximately one gallon per hour, with less fuel required at the higher temperature.

- Case I_7 is essentially the same as Case I_2 except an afterburner is operated at 1,400°F, greatly increasing fuel needs. Although there are apparently no plans to require afterburners on sewage sludge incinerators in the Boston area, such requirements exist in other parts of the country.
- Case I_8 represents a situation that is significantly different from the proposed Phase I facilities because raw sludge with a greater volatile solids content is incinerated. From the viewpoint of an energy balance around the incinerator, incineration of raw sludge offers the advantage of autogenous combustion at the lower filter cake solids content of 26% and at excess air as high as approximately 71%.

The heat balances presented in Table 2.3-5 can be used to develop unit process operating and maintenance (O&M) costs corresponding to a range of feasible operating conditions of the proposed Phase I incineration facilities at Deer Island. A summary of unit process incineration O&M costs is presented in Table 2.3-6 for Cases I_1, I_2, I_3, I_6 and I_7 assuming 1985 average daily sludge production of 255,000 lbs dry sludge solids input to furnaces.

The required manpower for operation of the proposed incineration facilities was taken from the Draft EIS. Electrical power consumption for fans, shaft motor and pumps was estimated to be 35 kw hr per wet ton sludge feed based on equipment manufacturer's recommendations (Allen 1977b). Start-up fuel requirements were assumed to be 600 gallons per start at one furnace start per 10 days. Case I_1 includes five gallons of oil per day for pilot burners. Annual costs for maintenance and materials were assumed to be 2% of capital costs of combustion and power generation facilities (detailed costs are presented in Appendix 3A).

Maintenance costs are difficult to estimate, but such costs for facilities constructed at Deer Island could be significant. The engineering study of existing MDC wastewater treatment facilities at Deer and Nut Islands by Kennedy Engineers notes the poor condition of many pieces of equipment on the islands. Much of the equipment deterioration may be attributed to the corrosive atmospheric environment. Also the high chloride content of the sludge may present particular problems for the O&M of incinerators. High chloride concentrations could result in clinker formation at the high temperatures in the combustion zone of the incinerators. Salts with low melting points can fuse and form clinkers, which can block drop holes between hearths or damage rabble arms.

As shown in Table 2.3-6, gross unit process O&M costs can roughly double when factors such as wetter cake, lower solids heat value and high excess air or the use of afterburners increase energy costs.

With respect to the benefits of waste heat recovery, electrical power production to offset the purchase of power from external sources is shown as a credit that lowers incineration unit process O&M costs. Corresponding to the EMMA study, a unit cost of $0.03/Kw hr is assumed for electrical energy. However, the actual value of power generated on-site may be slightly less because of demand charges for standby power from external sources. The relative benefit of waste heat recovery is greatest in Case I_1 where no auxiliary fuel is used, and the energy resource value of the sludge is recovered. The greater quantity of heat recovered in Case I_6 compared to Case I_2, for example, is an artifact of the greater mass of combustion gases resulting from incineration of a wetter sludge at higher excess air. A truer measure of the relative benefit of waste heat recovery may be Kw-hr produced per gallon of auxiliary fuel, which is approximately 96 Kw-hr per gallon in Case I_2 versus 10 Kw-hr per gallon in Case I_6. In Case I_7 where fuel is added

TABLE 2.3-6

SUMMARY OF UNIT PROCESS O&M COSTS - INCINERATION CASES

(1985 Average Daily Sludge Production)

Variable		Case I_1	Case I_2	Case I_3	Case I_6	Case I_7
				Labor		
Labor	manhours/day	123	123	123	123	123
	manhours/year	48,200	48,200	48,200	48,200	48,200
				Energy		
Electric	Kw-hr/day	11,200	14,900	17,200	17,200	14,900
	Kw-hr/year	$4.09x10^6$	$5.44x10^6$	$6.28x10^6$	$6.28x10^6$	$5.44x10^6$
Auxiliary Fuel Oil	gal/day	5	315	2283	4172	5117
	gal/yr	$1.82x10^3$	$1.15x10^5$	8.23x10	$1.52x10^6$	$1.87x10^6$
Start-Up Fuel Oil	gal/day (avg)	60	60	60	60	60
	gal/yr	$2.19x10^4$	$2.19x10^4$	$2.19x10^4$	$2.19x10^4$	$2.19x10^4$
Total Fuel Oil	gal/day	65	375	2343	4232	5117
	gal/yr	$2.37x10^4$	$1.37x10^5$	$8.55x10^5$	$1.54x10^6$	$1.89x10^6$
				Annual Costs		
Labor @ $6.84/manhour		$330,000	$330,000	$ 330,000	$ 330,000	$ 330,000
Electric @ $0.03/Kw-hr		123,000	163,000	188,000	188,000	163,000
Fuel Oil @ $0.38/gal		9,000	52,000	325,000	587,000	718,000
Maintenance @ 2%*		262,000	275,000	275,000	275,000	283,000
	Total O&M $/yr	$724,000	$820,000	$1,118,000	$1,380,000	$1,494,000
				Gross Unit Process O&M Cost **		
	$/dry ton input	$ 15.56	$ 17.62	$ 24.02	$ 29.65	$ 32.10
				Annual Revenue		
Power Sales -Kw-hr/day†		36,700	30,300	35,400	40,500	71,200
@ 0.03/Kw-hr, $/yr		$402,000	$332,000	$ 388,000	$ 444,000	$ 780,000
Net Annual O&M, $/yr		$322,000	$488,000	$ 730,000	$ 936,000	$ 714,000
Net Unit Process O&M Cost $/dry ton**		$ 6.92	$ 10.49	$ 15.69	$ 20.11	$ 15.34

*Maintenance cost based on 2% of capital cost of combination and power generation facilities only.

**Based on 127.5 dry tons/day input without costs of dewatering and ash disposal.

†Power sales at 87% utilization of average daily power production capacity.

to raise exhaust temperature to 1400°F in an afterburner, a significant portion of the incremental fuel cost between Case I_2 and Case I_7 is recovered by power generation.

To emphasize, the above costs are only incineration unit process O&M developed to indicate the variability of such costs. Complete systems alternatives including capital and annual costs are formulated in Section 3.

The question of whether or not the inclusion of waste heat recovery is truly cost-effective in these incineration cases can be best determined by analysis of the costs and benefits associated solely with waste heat recovery and power generation. Table 2.3-7 summarizes the annual cost of power generation and the potential power revenue and compares the cost of auxiliary fuel for each incineration case. For Cases I_1, I_2, I_3 and I_6, a power generation capacity of approximately 2,000 Kw would be required at a capital cost of roughly $3,000,000 (ENR 2200), which included boiler, turbine, condenser and additional building space. For Case I_7, which includes an afterburner operating at 1,400°F, a power generation capacity of approximately 4,000 Kw was assumed to be required, as in the pyrolysis cases considered in the following section, at a capital cost of roughly $3,400,000 (ENR 2200). Annual maintenance costs were assumed to be 2% of the capital cost.

From the data presented in Table 2.3-7, the use of waste heat recovery in Cases I_1, I_2, I_3 and I_6, where afterburners are not required, is marginal, with Case I_2 showing slightly less than break-even operation. For these cases, slight changes in the assumed discount rate, value of the energy produced or utilization factor could significantly affect the economics of the waste heat recovery. In Case I_7, where environmental concerns dictate the use of auxiliary fuel in an afterburner, recovering waste heat is more clearly beneficial.

In general, the first criterion for waste heat recovery is obviously that the revenue from the recovered heat (either steam or power sales) must pay for the annual cost of the recovery equipment, and any net revenue will be beneficial in offsetting other operating costs. Major uncertainties arise in estimating how large the net benefit may be due the influence of factors such as the value of the energy produced and its use. Admittedly, the use of auxiliary fuel in a sewage sludge

TABLE 2.3-7

COST EFFECTIVENESS OF WASTE HEAT FOR POWER GENERATION IN INCINERATION CASES

Variable	I_1	I_2	I_3	I_6	I_7
Recovery Equipment					
Capital cost (ENR 2200)	\$3,000,000	3,000,000	3,000,000	3,000,000	3,400,000
Annual cost, \$/yr (20 yrs @ 7%)	\$ 283,200	283,000	283,000	283,000	321,000
O&M @ 2% of capital	\$ 60,000	60,000	60,000	60,000	68,000
Total Annual Cost, \$/yr	\$ 343,000	343,000	343,000	343,000	389,000
Energy Recovered					
Kw-hr/day*	36,700	30,300	35,400	40,500	71,200
@ 0.03¢/Kw-hr \$/yr	402,000	332,000	388,000	444,000	780,000
Net Benefit of Waste Heat Recovery					
heat recovery, \$/yr	\$ 59,000	-11,000	45,000	101,000	391,000
Auxiliary Fuel Cost**					
@ \$0.38/gal \$/yr	0	44,000	317,000	579,000	710,000
% of fuel cost offset by waste heat recovery	-	0	14%	17%	55%

*Power credit at 87% utilization of average daily power production.

**Fuel cost at steady state without pilot fuel or start-up fuel.

incinerator is not the most efficient method of power production. However, given a situation where auxiliary fuel is mandated by environmental concerns or other external constraints, waste heat recovery is justifiable whenever projected revenues will clearly exceed the annual costs of the equipment. For all incinerator alternatives considered here, waste heat recovery will be included because some net benefit is shown under the assumptions as stated (except in Case I_2 where there is essentially no net effect). As stated in the Draft EIS, inclusion of waste heat recovery for the proposed incinerator facilities operating without afterburners must be justified by more detailed design considerations.

Air Quality Considerations

Applicable Standards

The 1977 Clean Air Act Amendments (1977 Amendments) define a major pollutant source as one that emits 100 tons of pollutant or more annually. The proposed primary sludge incinerator under design conditions is expected to emit approximately 117 tons of nitrogen oxides (NO_x) annually, thus making it a major source of NO_x. Emissions of the four other pollutants from the incinerator, for which ambient air quality standards have been promulgated, are expected to be less than 100 tons per year.

The Boston Metropolitan Air Quality Control Region (BMAQCR) has not yet been designated a nonattainment* area for nitrogen dioxide (NO_2). The designation of the BMAQCR will occur after public hearings slated for January 1978 (Dennis 1977). If the area is designated as non-attaining for NO_2, all new major sources of that pollutant must adhere to the Offset Policy as detailed in the 1977 Amendments.** All new sources must apply for permits. New sources that apply before July 1, 1979 will be issued permits in accordance with the 1976 Clean Air Act Interpretive Ruling. The only change made by the 1977 Amendments to the

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*Nonattainment area - an area where monitors have recorded contraventions of NO_2 standards.

**Offset policy - this policy requires a new source to guarantee a reduction in the emission of the pollutant under consideration by other sources at least as great as the contribution of the new source.

1976 Interpretive Ruling is that new source emissions may be incorporated into the State Implementation Plan (SIP), which is used as the base for offset emission calculations. This change does not affect the current study, however, as no new sources will be included in the Massachusetts SIP (Dennis 1977). New major sources under the Interpretive Ruling (and the Offset Policy for those proposed sources not included in the SIP) must meet an emissions limitation that specifies the Lowest Achievable Emissions Rate (LAER). Emission reductions that would more than offset the contribution of the applicable pollutant from the new source must be obtained from other local sources. Finally, a net positive air quality benefit must be shown with reasonable progress toward attaining applicable standards.

The EPA New Source Performance Standards (40 CFR Part 60), published in the Federal Register on March 8, 1974, were not changed by the 1977 Amendments. The New Source Performance Standard (NSPS) limits particulate emissions to no more than 0.65 g/kg of dry sludge input (1.30 lb per ton dry sludge input). NSPS limit visible emissions to less than 20% opacity, unless caused only by the presence of uncombined water. The EPA's Regulations on National Emission Standards for Hazardous Air Pollutants require that mercury emissions from sludge incineration and sludge drying plants not exceed 3,200 grams of mercury per 24-hour period (40 CFR Part 48292). The federal regulations do not contain specific criteria for odor control or afterburner temperature limits.

An EPA Technical Bulletin, Municipal Sludge Management Environmental Factors (FR Vol. 42 p. 57427), indicates that special measures should be taken to ensure at least 95% destruction of polychlorinated biphenyls (PCB), if PCB concentration in the sludge exceeds 25 mg/kg dry sludge.

The Commonwealth of Massachusetts does not have specific emission standards for sewage sludge incinerators. However, the Boston Air Pollution Control District requires that new municipal incinerators, typically refuse incinerators, meet 0.05 grains* per standard cubic foot, corrected to 12% carbon dioxide (CO_2).

The Massachusetts Department of Environmental Quality Engineering (DEQE) is now preparing revisions to incorporate a new hydrocarbon control plan. However, sewage sludge incinerators are not considered significant hydrocarbon sources and the new hydrocarbon control plan will not contain specific emission limits for sewage sludge incinerators. DEQE does not now plan to require afterburners on sewage sludge incinerators for the purposes of hydrocarbon control (Comproni 1977).

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*7,000 grains = 1 pound

The prospects for the proposed incineration facilities complying with the above air pollution control criteria are discussed in the following section.

Projected Emissions

Air pollutant emissions from the proposed incineration facilities at Deer Island have been estimated by H&E in the 1974 EAS for 1995 primary and secondary sludge conditions and more recently by EcolSciences in the 1976 Draft EIS for 1985 Phase I primary sludge. The emission factors used in the Draft EIS for sludge combustion controlled with water scrubbers are presented below:

- 1.3 lbs particulates/ton dry sludge solids,
- 2.0 lbs SO_2/ton dry sludge solids,
- 1.0 lb hydrocarbon/ton dry sludge solids,
- 5.0 lbs NO_2/ton dry sludge solids and
- negligible CO emission.

The particulate emission factor is required by NSPS and is obtained using venturi scrubbers operating at a pressure drop of approximately 20 to 40 inches water gauge (EPA 1975). Based on an uncontrolled particulate emission rate of 33 lbs particulate per ton dry sludge solids, in multiple-hearth furnaces, the NSPS is equivalent to a particulate collection efficiency of 96% (EPA 1975), which should be obtained using properly operated venturi scrubbers. Usually venturi scrubbers are designed so that the pressure drop can be adjusted over a range such as that above, thereby allowing manipulation of the pressure drop to achieve the required particulate control.

Initial compliance tests of new sludge incinerators are overseen by EPA regional enforcement sections. However, after initial compliance with NSPS is demonstrated, periodic monitoring and assurance of continued compliance with NSPS is normally left to state and local air pollution control district enforcement. Although data from some initial and routine compliance checks on incinerator emissions can be found in the National Air Data Bank at Research Triangle Park, NC, there is apparently no mechanism within EPA for the collection of emission data to verify the long-term compliance with NSPS of sewage sludge incinerators constructed with EPA grant funds.

With respect to Boston Air Pollution Control District incinerator particulate emission limit of 0.05 grains per standard cubic foot, an incinerator that complies with the NSPS emission limitation should also be in compliance with the local particulate concentration emission limit.

In the Draft EIS, an emission factor of 2 lbs SO_2 per ton dry sludge solids feed was used, without explanation, for estimating SO_2 emission of sludge combustion. The EPA's Compilation of Air Pollutant Emission Factors (1974a) indicates that uncontrolled SO_2 emissions are 1.0 lb SO_2 per ton dry sludge and controlled (wet scrubber) emissions are 0.8 lbs SO_2 per ton dry sludge (EPA 1974a). The EPA's Air Pollution Aspects of Sludge Incineration presents stack test data on five sewage sludge incinerators in which SO_2 emissions from sources with wet scrubbers range from "none detected" to approximately 1.6 lbs SO_2 per ton dry sludge solids (EPA 1975). In the February 14, 1975 letter from H&E to Mr. Martin Weiss appended to the 1974 EAS, H&E cite stack test data, possibly including EPA data used in the above EPA reports, which indicate SO_2 emissions from sludge incinerators to range from 0.4 to 1.6 lbs SO_2 per ton dry sludge solids with an average of 0.9 lbs SO_2 per ton. Based on these figures, the SO_2 emission factor used in the Draft EIS appears conservative (high), but possible.

In general, the sulfur content of sludge is low (less than 1% by weight of dry sludge solids). The presence of lime (after recalcining) in the furance may also contribute to prevention of SO_2 emission. From the above discussion, however, it is apparent that considerable uncertainty exists in selecting an SO_2 emission factor for sewage sludge incinerators.

The Draft EIS uses emission factors for hydrocarbons and NO_2 from the EPA's Compilation of Air Pollutant Emissions Factors (EPA 1974a). These emission factors are also averages of EPA stack test data, and actual emissions could vary greatly. In the EPA emission factor book, wet scrubbers are indicated to have removal efficiencies of 33% and 17% for hydrocarbons and NO_x, respectively (EPA 1974a).

Because these emission factors were based on information from EPA stack tests, these factors possibly include the emission from any auxiliary fuel burned with the sludge during those tests. Unfortunately, fuel requirements at the facilities tested are not provided in the referenced reports. Generally, emissions from No. 2 fuel oil combustion would be insignificant compared to emission from sludge cake combustion, except for SO_2 and NO_2 emissions when large quantities of auxiliary fuel are used.

The Draft EIS added projected emissions from auxiliary fuel requirements to emissions from sludge combustion based on the above emission factors. This procedure is conservative, that is, it results in higher emissions to the extent that fuel use may be already included in the sludge emission factor. Presumably, the NSPS of 1.3 lbs particulate/ton dry sludge must be met regardless of what fraction of the particulate emissions is from fuel combustion.

Projected incineration air pollution emissions and emissions from various levels of auxiliary fuel use (corresponding to heat balance cases presented previously) are summarized in Table 2.3-8. The emissions from sludge combustion are based on the emission factors discussed above as presented originally in the Draft EIS. Emissions from combustion of No. 2 fuel oil are based on emission factors from a recent supplement to the EPA's Compilation of the Air Pollutant Emission Factors corrected for assumed wet scrubber efficiencies discussed previously.

The projected annual emissions indicate total annual emissions of approximately 30 tons of particulates, 47 to 65 tons of SO_2, 23 tons of hydrocarbon (negligible with afterburner), and 117 to 134 tons of NO_2. Carbon monoxide emissions would be minimal in all cases. With respect to the EPA emission offset requirements, the Phase I facilities would be considered a major source of NO_2. If the Boston AQCR is designated as

TABLE 2.3-8

SUMMARY OF PROJECTED INCINERATION AIR POLLUTION EMISSIONS

(1985 Conditions)

Emissions	Sludge Combustion @ 127.5 dry tons/day (all cases)		Oil Combustion by Case*					Total Emission Sludge and Oil By Case* (lbs/day)				
(lbs/day)	(lbs/day)	(kg/day)	I_1 (65gpd)	I_2 (375gpd)	I_3 (2,343gpd)	I_6 (4,232gpd)	I_7 (5,177gpd)	I_1	I_2	I_3	I_6	I_7
Total Suspended Particulates	166	(75)	-**	-	-	-	-	166	166	166	166	166
Sulfur Dioxide	255	(116)	1.3	7.3	45	81	100	256	262	300	336	355
Carbon Monoxide	Neg.	(Neg.)	0.3	1.9	12	21	0.3†	0.3	1.9	12	21	0.3†
Hydro Carbons	127	(58)	0.0	0.3	1.6	29	0.1†	127	127	129	130	1.3†
Nitrogen Oxides	638	(289)	1.2	6.8	43	77	95	639	645	681	715	733

*Cases correspond to those in Tables 2.3-5 and 2.3-6.

**Any particulate emissions from fuel combustion are assumed to be included in the allowable NSPS of 1.3 lbs particulate/ton dry sludge solids, a standard that must be met under all fuel use conditions.

†Afterburner removal efficiency of 99% assumed for CO and hydrocarbons.

nonattainment for NO_2, implementation of the Phase I incineration facilities could require an emission offset. In addition to these major air pollution indices, emissions of metals and toxic organics must also be considered.

Data on metal emissions are presently limited. One of the first attempts to gather information on metals in emissions from many sewage sludge incinerators was the 1972 EPA Task Force Report (EPA 1972). The information in the original 1972 report has been augmented occasionally by individual plant tests, such as the 1974 tests of sewage sludge incinerators at the Piscataway incinerator in Accokeck, MD (Cottrell 1975). The EPA is presently planning to update information on metal emissions from sewage sludge incinerators by conducting a new series of tests at the sewage treatment plants around the country (Wall 1977). One of the points considered by the new EPA incinerator study will be the relative distribution of metals between incinerator ash and particulate matter.

Discussions of existing data on heavy metal emissions from sewage sludge incinerators are presented in the Draft EIS and the 1974 EAS by H&E. One of the major uncertainties with respect to metal emissions is the extent to which specific metals are vaporized during combustion. Metals vaporized during combustion could be emitted in gaseous form or, more likely, adhere to particulate matter during condensation, thus enriching the metal concentration in the particulates emitted and collected in the scrubber water. The original 1972 EPA Task Force Report found, based on limited data, that such metal enrichment was not apparent for many heavy metals, except mercury and possibly lead (EPA 1972). More recent testing at the Palo Alto, CA sludge incinerator showed less than 1% of lead input in sludge was emitted (Camp, Dresser and McKee and Potter 1976). According to EPA's publication on the Air Pollution Aspects of Sludge Incineration, volatization of mercury presents special problems, but it is believed that other hazardous metals "will not disproportionately appear in stack gases" (EPA 1975). Other hazardous substances that could volatize during combustion include cadmium and beryllium; however, existing emissions data on these metals are limited. The new EPA sludge incinerator emission study is planned to answer these questions concerning the fate of heavy metals during combustion by performing material balances for many metals (Wall 1977).

The Draft EIS presented an estimate of mercury emissions using a mass weighted average mercury concentration of 14.2 ppm in the combined sludges from Deer and Nut Islands. This value appears to be a worst case based on data for January through June 1973. The weighted average concentration for mercury for 1973 to 1977 is 6.8 ppm. Data presented in EPA's background document for the mercury emission standard of 3200 g Hg per day indicated that mercury removal efficiencies of water scrubbers at five different incinerators varied from a high of 96% to a low of 68% (EPA 1974b). In the EIS, a conservative mercury removal efficiency of 60% was assumed resulting in an emission rate of 657 g/day. Using a projected mercury concentration of 6.8 ppm and 90% removal efficiency, the average mercury emission rate would be 79 g/day. Thus, the projected atmospheric emissions of mercury from the Phase I incinerators could range from 530 to 64 lbs/year.

The Draft EIS projected that emission of stable, toxic organic substances such as PCBs would be negligible because of low concentrations in the sludge and the thermal destruction provided by high temperatures (1,400-1,700°F) during sludge combustion. However, where furnace design allows some organics to be vaporized on upper hearths before reaching the combustion zone of the incinerator, these organic materials could escape destruction. This possibility could explain an average PCB destruction rate of only 94% in tests at a sewage sludge incinerator in Palo Alto, CA (Jacknow 1976). Region I EPA is currently conducting tests of PCB emissions and removals at a seven-hearth sludge incinerator with a wet scrubber at New Bedford, MA (Stonefield 1977).

Air Quality Modeling and TSP Background Concentrations

Air Quality Modeling

EcolSciences' calculations of air pollutant emissions from the proposed incineration facilities in the 1976 Draft EIS were revised by ERT as discussed in the previous section. Design operating parameters and emission rates (for Case I_2) are presented in Table 2.3-9. The emission rates presented include the emissions associated with both sludge incineration and the combustion of supplemental fuel.

TABLE 2.3-9

1985 DESIGN OPERATING PARAMETERS

Variable	Value
Number of Stacks	2
Dry Sludge Loadings	127.5 tons/day
Pollutant Emissions	
Particulate	166 lbs/day
Sulfur Dioxide	262 lbs/day
Carbon Monoxide	1.9 lbs/day
Hydrocarbons	127 lbs/day
Nitrogen Oxides	645 lbs/day
Stack Parameters	
Height	110 feet
Inside Diameter	3 feet
Exhaust Gas Parameters	
Exit Temperature	120°C
Exit Velocity	10 m/s
Flow	13,328 ACFM

In the 1976 Draft EIS, the EPA model PTMAX was used to determine worst-case concentrations of plant-related pollutants. Although concentrations were calculated for all stability categories and the largest concentrations were shown to occur during unstable conditions, a neutral atmosphere was assumed to be a worst case because of its frequency. Logan Airport data show that unstable conditions occur, therefore the higher concentrations, which are associated with unstable conditions, should be considered in the short-term analysis. For longer-term concentrations (daily and annual), sequential meteorological records should be used. The EPA, in its forthcoming Air Quality Modeling Guidelines, recommends the use of five years of sequential meteorological data. Such a record is available for Logan Airport from the National Climatic Center in Asheville, North Carolina. Annual and maximum 24-hour average plant-related pollutant concentrations can be estimated with the use of the sequential meteorological data. Alternatively a windrose giving the frequency of each combination of weather conditions (atmospheric stability, wind speed, wind direction and mixing depth) can be used to estimate annual average concentrations. If sequential meteorological data are not used, 24-hour averages would have to be estimated either using the Federal Register Method, which assumes a lidded condition for six hours, or assuming a directionally persistent high wind speed, neutral atmosphere condition that persists throughout the 24-hour period.

Two assumptions about downwash were made in the 1976 Draft EIS: (1) building downwash could be prevented using 110-foot stacks and (2) stack downwash could be prevented with a stack gas exit velocity of 10 m/s. Both assumptions are true only for very low wind speeds. To avoid building downwash, an effective stack height of 2.5 times the building height is required or a stack of 42 meters (138 feet). The plume rise as calculated using the Briggs' equations (Briggs 1969) reaches a maximum of 20 meters under very light wind speeds and unstable or neutral conditions. Plume rise is suppressed during stable atmospheric conditions. When added to the design physical stack height of 33 meters, the effective height becomes 53 meters. Because wind speeds increase with height, to compare speeds recorded at Logan Airport, where measurements are made at approximately 20 feet above the ground, to the winds at the top of the proposed 110-foot stack, a power law equation can be used (Turner 1970).

$$U_s = U_o \left(\frac{H_s}{H_o} \right)^P$$

where

U_s is the wind speed at stack top height

U_o is the wind speed at monitored height

H_s is the height of the stack

H_o is the height of the measurement

P varies with stability

For these calculations P was assumed to be 0.09. This is a conservative value in that it assumes a very well-mixed (unstable) atmosphere, which implies a small wind speed variation with height.

A monitored wind speed of 4 m/s would then correspond to a 5 m/s wind speed at the stack top. The plume rise is reduced to 7 meters for a stack top wind speed of 5 m/s. Therefore, building downwash can be expected to occur when wind speeds, as recorded at Logan Airport, are greater than 4 m/s (89% of the time). Similarly, stack downwash can be expected to occur when wind speeds at stack height are greater than 2/3 times the flue gas exit velocity or 7 m/s for the design parameters. Wind speed data collected at Logan Airport show winds in excess of 15 mph approximately 56% of the time at stack height (13 mph as measured 20 feet about the ground). This particular problem of stack downwash could be minimized with a single stack exhausting the same volume of stack gases, therefore doubling the exit velocity.

Background Particulate Concentration Estimations

Background particulate concentrations are those levels that can be attributed to the aggregate of the sources in the area, excluding the source in question. TSP concentrations monitored during 1974 by the state-operated shelter in Revere were used in the 1976 Draft EIS to estimate background levels of particulates for the proposed sludge incineration site on Deer Island. Although particulate levels monitored at this site are expected to be higher than the actual levels on Deer Island, a brief review of the state monitoring site locations reveals that none of the other state monitoring locations are more representative. Therefore, monitoring data from the same site were used in the present study.

Five years of monitoring data (October 1972 to September 1977) were compiled to fit the criteria specified in Larsen's most recent paper (Larsen 1977). The arithmetic mean and geometric standard deviation of the data were calculated to be 54.85 and 1.58, respectively. According to the tabulation in the 1977 article, the ratio of the annual 24-hour maximum to the geometric mean is 3.45, yielding a maximum expected background concentration of 189 $\mu g/m^3$. The second highest concentration is expected to be 2.98 times the geometric mean of the data or 163 $\mu g/m^3$. These values are higher than background concentrations assumed in the 1976 Draft EIS, but are felt to be more accurate because a larger data base and a refined model are used.

Conclusion

This review of the analysis done by EcolSciences in the 1976 Draft EIS for the Boston Metropolitan Incinerator has shown that some of the assumptions made by EcolSciences have caused an underprediction of the worst-case concentrations. All stability categories should have been considered in the worst-case category solution. Also, corrections for both stack and building downwash should have been included in the point source modeling process,. A review of the most recent five years of TSP monitoring data in the area show that higher background concentrations than those that were assumed by EcolSciences can be expected. These increases in calculated worst-case TSP concentrations are not expected to be large enough to cause the primary standard to be exceeded, however, both the highest and second highest background concentrations alone (as determined using Larsen's method) exceed the 24-hour secondary standard.

Residuals Disposal

Scrubber Water

The scrubber water used in venturi and impingement tray scrubbers on multiple-hearth sludge incinerators will contain collected particulate matter. To the extent that any metals are vaporized during combustion, the collected particulates can contain greater concentrations of these metals than would be found in the ash.

Little data are available on the concentrations of stable organic compounds such as PCBs or pesticides in scrubber water. Presumably most of this material is destroyed during combustion. EPA's report on the Air Pollution Aspects of Sludge Incineration states that in sampling at five plants, no PCBs were detected (<1 ppb) in scrubber water (EPA 1975). Current testing for PCBs at the New Bedford, MA, sludge incinerator now being directed by Region I EPA should add information on this point.

The scrubber water from the proposed incineration facilities at Deer Island would be recycled to the existing wastewater treatment plant. A recent sludge management study performed for the New York-New Jersey-Connecticut Interstate Sanitation Commission recommended that scrubber water from similar facilities be treated separately "to avoid recycling of heavy metals and resultant build up of heavy metals in the sludge" (Camp, Dresser and McKee and Potter 1976). It was recommended that scrubber water receive lime treatment using rapid mix, flocculation and sedimentation facilities. Sludge from the scrubber water treatment would be separately dewatered on filter presses and disposed in proper landfills. If detailed design indicates that separate treatment of scrubber water is required, additional capital and operating costs will be increased above those estimated for the incineration alternatives presented in the Draft EIS.

Ash Disposal

Three basic alternatives for ash disposal, including on-site landfill, off-site landfill and ocean dumping, are considered in the Draft EIS. Ocean dumping is the least-cost method, but its feasibility is limited by existing federal policy on ocean dumping. The environmental impacts related to increased turbudity and metal contamination of marine waters resulting from ocean dumping of ash are similar to those of ocean dumping of dewatered, digested sludge except for the smaller total solids quantity with ash. The environmental aspects of ocean dumping are discussed in a following section.

Considering landfill of ash, the major environmental concern is the long-term prevention of metal leaching into groundwater or surface waters. Leachate control can mean many things, and with respect to state approved landfills in Massachusetts, the adequacy of leachate control is determined on a case-by-case basis. Generally leachate control is accomplished by (1) providing some impenetrable barrier between the contained residual material and/or (2) collecting leachate and runoff.

In some cases a natural impenetrable barrier can exist because of impermeable soil conditions. Also, as proposed in the Draft EIS for on-site landfill at Deer Island, an impenetrable barrier can be constructed such as that proposed, with the cellular cofferdam and plastic liner. The permanence of the barrier is an uncertainty that faces the planner, because, as indicated in review comments to the Draft EIS, cofferdams and plastic liners are subject to deterioration or rupture.

Leachate and runoff collection can also be provided, as at the state-approved landfill site in Plainville. Collected leachate is commonly returned to the landfill area, and evaporation is the ultimate recycle of the liquid portion. Sizing facilities, which are adequate to collect flows resulting during storms of some design frequency, are an important factor in the design of runoff and leachate collection systems.

Recognizing that barriers and collection systems are not perfect, the ability of toxic materials to be leached from the ash must be considered. Assuming no losses by vaporization during combustion, most metal concentrations in the ash would be greater, on a dry weight basis, than they were in the original dry sludge solids because of the removal of the volatile portion of the dry solids. However, the total daily mass of metals input to the landfill would be the same as if the dewatered sludge were landfilled directly.

It has been reported that metals in ash are generally in the less soluble oxide form (Jacknow 1976). The 1973 H&E study presented information on the solubility of some metals from simulated digested sludge and ash in distilled water and weak acid (citrate). The solubility tests consisted of 24-hour contact with solvent, filtration and then analysis of metal content. Compared to digested sludge, ash showed increased solubility of cadmium, copper and possibly silver but decreased solubility of chromium, nickel and zinc. Lead showed no detectable solubility in water or citrate for either digested sludge or ash.

At present, it appears that insufficient information exists to predict metal emissions in ash leachate and resultant environmental impacts. The choice between on-site and off-site ash disposal, since economic factors are similar, must be made on the uncertain basis of assumed differences in the reliability of the barriers provided at each site. With an attitude of minimizing risk, the Draft EIS decided against on-site landfill of ash because of the proximity of the landfill to the marine environment.

Impact of Sludge Management Issues

Secondary Sludge Considerations

A major question, which must be considered when primary sludge management planning is performed separately from planning for secondary sludge disposal, is whether or not proposed primary sludge facilities foreclose future options for secondary sludge. Also, the suitability and flexibility of expanding primary sludge facilities to also handle secondary sludge must be considered.

The proposed Deer Island incineration facilities appear to be sized to handle the projected 1985 undigested sludge quantities. The three proposed incinerators are 25 ft-9 in. nine-hearths, with two operating in 1985 plus one standby. Estimates by Envirotech Corporation indicate that three smaller furnaces at 22 ft-3 in. nine-hearths would be adequate for projected 1985 digested sludge quantities. As shown in Table 2.3-5, there are advantages to operating incinerators with raw sludge, and the eventual phase-out of anaerobic digesters was recommended in the proposed sludge management plan. To the extent that proposed Phase I incinceration capacity would be fully used for incineration of raw primary sludge after 1985, the proposed Phase I facilities do not prompt incineration of secondary sludge through a need to use idle incinerator capacity.

The proposed Phase I plan does include the construction of some facilities that would facilitate expansion for secondary sludge incineration. The proposed sludge handling building on Deer Island, as shown in the 1973 report, includes space for an additional incinerator and two vacuum filters. Also, the sludge pipeline across the harbor is sized to handle primary and secondary sludge from Nut Island. If this incremental capacity is inconsistent with ultimate secondary sludge management, the investment will be lost.

With respect to construction of secondary sludge capacity, EPA's emission offset policy could interfere. Although the Phase I facilities will emit less than 100 tons per year of particulates, the addition of four more incinerators will probably produce emissions that exceed this rate, especially if 50 tons per year becomes the definition of a major source. Unless air quality monitoring and modeling shows the Deer Island area to be a clean air area and the expanded incineration capacity to have negligible impact on adjacent nonattainment areas, an emission offset could be required. It should be noted that EPA's plans to monitor air quality around Deer Island were abandoned this year because the Phase I incinerators would not be a major particulate source and the Boston area has not been designated as nonattainment for NO_2.

Pretreatment to Reduce Metals in Sludge

Pretreatment resulting in decreased metals in sludge that is incinerated will reduce environmental concerns about metal emissions to the air and possible leaching from ash. Therefore, pretreatment would make incineration more useful.

Transportation Considerations

Because barging and trucking of ash is less costly on a unit basis than transport of liquid or dewatered sludge, the incineration option would be less affected by changes in transportation costs.

2.3.2 Pyrolysis

Description of Process

In the strictest sense, pyrolysis means the thermal decomposition or destructive distillation of organic matter in the absence of oxygen. However, most pyrolysis systems now being developed and pilot tested for use on sewage sludge or solid waste use reactor (furnace) conditions in which oxygen exists, but in insufficient quantities to support complete combustion, that is, so-called oxygen-deficient atmospheres. The products of the thermal decomposition process can be gases, liquids or solid char, or combinations. The gases and liquids will have a fuel value because of their combustible organic content, as will the char, which also contains some combustible matter along with the residual ash.

For large scale applications, current prototype reactors include rotary kilns, shaft furnaces and multiple-hearth furnaces. Heat for the process is provided by auxiliary fuel or combustion of part of the input waste. Most large scale pilot tests have thus far used solid waste or solid waste plus some sewage sludge. However, for pyrolysis of sewage sludge alone, multiple-hearth furnaces appear to be the most imminent technology. When pyrolysis is accomplished in multiple-hearth furnaces, the goal is to maximize fuel gas production, minimize char production and avoid liquid product formation.

Pyrolysis of sewage sludge in multiple-hearth furnaces was recently recommended for treatment plants within the highly urbanized areas of the New York-New Jersey metropolitan area (Camp, Dresser and McKee and Potter 1976). A full scale demonstration test of pyrolysis of sewage sludge in a multiple-hearth furnace (16 ft-9 in. six-hearth) was recently conducted in Concord, CA for the Central Contra Costos Sanitary District (Brown and Caldwell 1977). Although the purpose of the Concord study was to investigate the combustion and pyrolization of combined sludge and refuse derived fuel (RDF) to minimize auxiliary fuel requirements, pyrolysis of sewage sludge without RDF was accomplished, but not without auxiliary fuel for the sludge conditions during the test (combined primary and trickling filter sludge at 24% solids).

For the purposes of this study, pyrolysis of sludge in multiple-hearth furnaces appears to be the technology most suitable plan for incorporation into the recommended MDC sludge management plan. Because of the similarity between proposed multiple-hearth incineration facilities and those required for pyrolysis, dewatering equipment and sludge building layouts are similar in both cases.

The equipment required for pyrolysis of sludge in a multiple-hearth furnace is essentially the same as that required for incineration of sludge, except that an afterburner for combustion of fuel gas is required in all cases. As with incineration, sludge is fed into the furnace on the upper hearth and then descends from hearth to hearth as it is moved along by rabble arms. However, the temperature profile is different from the incineration mode.

The upper hearths are used for sludge drying, with exit gas temperatures of approximately 700 to 800°F. In the pyrolysis mode, temperatures increase on lower hearths to a maximum of 1,500°F to 1,600°F compared to maximum incineration temperatures of 1,700°F to 1,800°F. The high temperatures on lower hearths are maintained by burning some fraction of the combustible matter in the sludge. Char containing approximately 4 to 5% of the input combustible matter is discharged from the bottom hearth at approximately 1,500°F. Ash or char cooling is provided externally by indirect heat exchanges, which are thermal disk coolers that rotate in the ash and through which cooling water passes. The char is cooled to about 300°F for pneumatic conveyance to storage bins, although temperatures around 600°F can be tolerated if char is conveyed by screw or bucket conveyor. If waste-heat boilers are used, the thermal disk coolers can be used to preheat boiler water.

The temperature profile in the pyrolysis mode is established and controlled by the amount of air injected in each hearth. Whereas incinerators operate under slight vacuum (approximately 0.1 in H_2O) produced by the ID fan, in the pyrolysis mode, air is injected in a controlled manner on certain hearths. The amount of air injected on various hearths can be controlled by temperature sensors on the hearths. To produce fuel gas, only enough air is injected to maintain the temperature required for the destructive distillation process. The percent by weight of the total sludge combustibles that must be burned in the furnace to maintain temperatures increases as the wetness of the sludge cake increases. The quantities of air added in the furnace will be below stoichiometric requirements.

The fuel gas produced in the furnace is drawn off by the ID fan, then combusted in the afterburner. Excess air in the afterburner will be 40 to 50% of theoretical requirements for the combustible content of the gas. The combustible fraction of the pyrolysis gas will contain methane, hydrogen, CO and higher hydrocarbons. Afterburner temperature would be maintained at a minimum of 1,400°F, although, with sufficient cake dryness resulting in more combustibles in the gas, higher temperatures may be possible.

Some potential advantages of the operation of multiple-hearth furnaces in the pyrolysis mode include:

- less particulate entrainment due to lower gas velocities at lower gas volume in the furnace;
- lower fuel requirements due to overall lower excess air requirements (compared to conventional incinerators) and
- lower furnace temperature, which avoids clinker formation and reduces radiation loss.

There have been no long-term full scale applications of sludge pyrolysis in multiple-hearth furnaces or any other furnace. However, the required hardware, such as the multiple-hearth furnace and afterburner, has been developed through many years of application in the incineration mode. Multiple-hearth furnaces have been used successfully for production of charcoal in a pyrolysis mode where char production is maximized.

The dewatering equipment required for pyrolysis of sludge in multiple-hearth furnaces is the same as that required for incineration. Drier filter cakes reduce auxiliary fuel requirements by reducing the fraction of combustible matter burned in the furnace to provide heat for the process.

Review of Local Studies

Havens and Emerson Reports

The 1973 study of sludge management alternatives did not evaluate pyrolysis of sewage sludge because it was not one of the alternatives recommended by the April 1972 Boston Harbor Pollution Task Force study. In 1972, pyrolysis was still in the research stage and, as such, was probably eliminated as high-risk technology.

EPA Draft EIS

The 1976 Draft EIS mentioned, but eliminated, pyrolysis as an alternative volume reduction process. Pyrolysis was eliminated for two basic reasons: (1) problems in treating liquid sidestreams resulting from distillate separation and (2) a bench-scale test indicating that no net energy would be available at less than 43% solids.

The Draft EIS did not describe in detail the pyrolysis process that would produce the liquid sidestream containing "water soluble short-chain organic compounds." As discussed above, pyrolysis in multiple-hearth furnaces would be designed to maximize fuel gas production without forming an organic liquid sidestream. Because the hydrocarbons in the pyrolysis gas would be burned in the afterburner, it is unlikely that there would be any appreciable accumulation of organic compounds in the scrubber water.

With respect to the energetics of pyrolysis, the major difference between the proposed Phase I incineration facilities (using low excess air) and pyrolysis in multiple-hearth furnace is the necessity of an afterburner for combustion of pyrolysis gas. Because the total heat value of the sludge feed is the same whether it is burned in the furnace or in the afterburner, the major difference in the fuel requirement in the pyrolysis case (also at 50% excess air) will be the incremental fuel needed to raise the temperature of the combustion gases and air from the incinerator exhaust conditions to the desired afterburner temperature, for instance, 1,400°F. If an afterburner is required on the incinerator, auxiliary fuel requirements in the two cases would be similar. A more detailed discussion of energy requirements for pyrolysis is presented in the following section.

Energy Considerations

The major process variables previously identified for incineration would also be key parameters in the optimization of pyrolysis furnace operation. As was done for incineration, heat balances were performed on a number of cases representing a range of feasible pyrolysis operating conditions. Again the heat balances were calculated by a proprietary computer program from Envirotech Corporation. A summary of the pyrolysis cases considered, showing input variables and resulting auxiliary fuel requirements, is presented in Table 2.3-10.

A conservative excess air value of 50% was used in all pyrolysis cases; however, in practice, excess air values of 40% would probably be satisfactory (Allen 1977c).

Case P_1 corresponds to pyrolysis of anaerobically digested sludge (having the design heat value of 5595 Btu/lb day sludge volatile solid) that has been dewatered to 40% solids. With the required afterburner temperature of 1,400°F, this case is not autogenous and requires 20 gallons per hour per furnace of No. 2 fuel oil.

Case P_2 also corresponds to anaerobically digested sludge, but a filter cake at 30% solids is used. With an afterburner temperature of 1,400°F, Case P_2 is essentially the same as Case I_7 where an afterburner is added to an incinerator. The maximum auxiliary fuel requirements for Case P_2 and Case I_7 are 135 gph per furnace and 130 gph per furnace, respectively. The slightly greater fuel use in Case P_2 is due to the greater loss of heat in the char discharged from the furnace at 1,500°F. Also, the char contains 4 to 5% of the input volatile matter, the heat value of which is not used in the furnace.

Case P_3 represents a worst case in which anaerobically digested sludge of low heat value (5,000 Btu per lb dry sludge solids) in a filter cake of only 26% solids is pyrolyzed.

Case P_4 represents an optimal situation for pyrolysis. In Case P_4, undigested sludge with a heat value of 7,570 Btu/lb dry sludge solids is pyrolyzed after dewatering to 40% solids. A maximum autogenous temperature of 1,700°F is achieved in the afterburner. Although theoretically

TABLE 2.3-10

SUMMARY OF PYROLYSIS HEAT BALANCE CALCULATIONS

(1985 conditions)

Variable	Case P_1	P_2	P_3	P_4
Lbs dry sludge/day (total)				
average	255,000	255,000	255,000	469,000
maximum	312,000	312,000	312,000	574,000
% volatile solids	50.5	50.5	50.5	68.3
Btu/lb VSS	11,080	11,080	9,900	11,080
% solids in cake	40	30	26	40
Base temp. of sludge, °F	60	60	60	60
Base temp. of air, °F	60	60	60	60
Moisture in air, lb H_2O/lb air	0.01	0.01	0.01	0.01
Excess air, % of theoretical air for volatile solids*	50	50	50	50
Exhaust gas temp., °F	1,400	1,400	1,400	1,700
Boiler exhaust gas temp., °F	450	450	450	450
Ash temp., °F	1,500	1,500	1,500	1,500
Shaft air return %*	100	100	100	100
No. of furnaces operating	2	2	2	2
Furnace size (diam.-hearths)	22'-3" x 9H	22'-3' x 9H	22'-3" x 9H	25'-9" x 8H
Auxiliary fuel (max. day)				
No. 2 oil, gph/furnace	20	135	258	0
Btu/hr/furnace x 10^6 @ 143,000 Btu/gal	2.86	19.3	36.9	0

*Excess air and shaft return air are inputs to the afterburner.

a similar temperature could be achieved in the incineration mode under similar cake dryness and excess air conditions, the pyrolysis mode of operation is better suited to properly control the process. As a practical matter, temperatures of 1,700°F would not be allowed in upper hearths of an incinerator, and excess air would be increased to provide cooling (Allen 1977a). Increased excess air rates would result in greater gas velocities and particulate entrainment in the furnace. Allowing the temperature to rise to 1,700°F in an external afterburner in a more controlled fashion would minimize particulate entrainment and maximize potential waste-heat recovery.

The heat balances presented in Table 2.3-10 can be used to develop unit process O&M costs corresponding to a range of pyrolysis operating conditions for reduction of the projected Phase I sludge quantities. A summary of unit process pyrolysis O&M costs is presented in Table 2.3-11 for Cases P_1, P_2 and P_3 for the 1985 average daily digested and dewatered sludge production of 255,000 lbs of dry sludge solids. As was done for the incineration cases, the average daily auxiliary fuel requirements were assumed to be 82% of the maximum daily requirement based on tightly controlled excess air rates and minimal radiation losses.

As indicated in Table 2.3-11, the O&M costs for multiple-hearth pyrolysis furnaces are more sensitive to suboptimal conditions of lower sludge heat value and wetter sludge cake. This situation results from the need to maintain an afterburner temperature of 1,400°F in all cases using auxiliary fuel.

With respect to fuel costs, the advantages of pyrolysis in multiple-hearth furnaces would be greatest when compared to conventional incinerators operating at 75% excess air or greater and equipped with afterburners. In such cases, there could be substantial fuel savings based on different excess air requirements alone (40% excess air in pyrolysis versus 75% excess air in incineration). Compared to the proposed Phase I incineration facilities operating at low excess air (50%) and without afterburners, the pyrolysis mode is more expensive to operate. Should afterburners be required on the Phase I facilities, both systems would be roughly equivalent in terms of operating expense. Pyrolysis would have potentially lower particulate emissions, reduced clinker formation and better temperature control.

TABLE 2.3-11

SUMMARY OF UNIT PROCESS O&M COSTS - PYROLYSIS ALTERNATIVES

(1985 average daily sludge production)

Variable	Case		
	P_1	P_2	P_3
Labor		Labor	
Manhours/day	123	123	123
Manhours/year	48,200	48,200	48,200
		Energy	
Electric			
Kw-hr/day	11,200	14,900	17,200
Kw-hr/year	4.09×10^6	5.44×10^6	6.28×10^6
Auxiliary fuel oil			
Gal/day	787	5314	10,155
Gal/year	2.87×10^5	1.94×10^6	3.71×10^6
Start-up fuel oil			
Gal/day (avg.)	60	60	60
Gal/year	2.19×10^4	2.19×10^4	2.19×10^4
Total fuel oil			
Gal/day	847	5374	10,215
Gal/year	3.09×10^5	1.96×10^6	3.73×10^6
		Annual Costs	
Labor @ $6.84/manhour	330,000	330,000	330,000
Electric @ $0.03/kw-hr	123,000	163,000	188,000
Fuel oil @ $0.38/gal	117,000	745,000	1,417,000
Maintenance @ 2%*	283,000	283,000	283,000
Total O&M $/year	853,000	1,521,000	2,218,000
		Gross Pyrolysis O&M Cost**	
$/dry ton input	18.33	32.68	47.66
		Annual Revenue	
Power sales			
Kw-hr/day†	44,400	62,200	81,400
@ $0.03/Kw-hr, $/year	486,000	681,000	891,000
Net annual O&M, $/year	367,000	840,000	1,327,000
Net unit process O&M cost**			
$/dry ton	7.89	18.05	28.51

*Maintenance cost based on 2% of capital cost of combustion and power generation facilities only.

**Based on 127.5 dry tons/day input without costs of dewatering and ash disposal.

†Power sales at 87% utilization of average daily power production capacity.

Although not considered here in detail, an investigation of the cost effectiveness of immediate curtailment of anaerobic digestion is recommended to optimize the performance of incinerators or pyrolyzers.

As was done for the incinerator cases, the costs associated with waste heat recovery in the pyrolysis mode have been analyzed separately as shown in Table 2.3-12. In the pyrolysis mode where the use of afterburners is an integral part of the process, waste heat recovery appears justifiable.

Air Quality Considerations

Applicable Standards

There are currently no emission standards specific for pyrolysis of sewage sludge. Presumably, the standards discussed previously for sludge incinerators would apply to pyrolysis of sludge in multiple-hearth furnaces.

Because it is possible to meet NSPS of 1.3 lbs particulate per ton dry sludge feed in multiple-hearth incinerators, it should be possible to provide even lower emissions or use less energy to achieve the NSPS limit in the pyrolysis mode. Because the particulate matter is larger in the pyrolysis mode (Brown and Caldwell 1977), scrubbers will have greater removal efficiency at a given pressure drop. Also, compared to conventional incinerators operating at 75% excess air, the pyrolysis mode at 40% excess air would result in a total gas volume reduction with associated reductions in scrubber cost, fan cost and electricity use.

Projected Emissions

Because the NSPS emission limit of 1.3 lbs particulate per ton dry sludge feed could be obtained, and assuming there is no incentive to operate the scrubbers at a greater pressure drop than necessary to achieve NSPS, as a worst case, it can be assumed that particulate emissions from pyrolysis would be the same as those projected for incineration. Because all pyrolysis cases include afterburners operating at 1,400°F (or greater), emissions of CO, hydrocarbons and stable organics such as PCBs should be negligible.

TABLE 2.3-12

COST EFFECTIVENESS OF WASTE HEAT RECOVERY IN PYROLYSIS CASES

Variable	P_1	P_2	P_3
Recovery equipment			
Capital cost (ENR 2200)	\$3,400,000	\$3,400,000	\$3,400,000
Annual cost, \$/yr (20 yr @ 7%)	321,000	321,000	321,000
O&M @ 2% of capital, \$/yr	68,000	68,000	68,000
Total annual cost, \$/yr	389,000	389,000	389,000
Energy recovered			
Kw-hr/day*	44,400	62,200	81,400
@ \$0.03/kw-hr, \$/yr	486,000	681,000	891,000
Net benefit of waste heat recovery, \$/yr	97,000	292,000	502,000
Auxiliary fuel cost** @\$0.38/gal, \$/yr	109,000	737,000	1,409,000
% of fuel cost offset by power generation	89%	40%	36%

*Power credit at 87% utilization of average daily power production.

**Fuel cost at steady state without pilot fuel or start-up fuel.

Very little data are available on the emissions of sulfur compounds and NO_x. Limited sampling for these compounds (9 samples for SO_2 and 13 tests for NO_x) was conducted during the testing of the pyrolysis of RDF and sludge at Concord, CA (Brown and Caldwell 1977). Although it may not be possible to generalize concentration values, the relative concentration of SO_2 was found to be greater in the afterburner inlet and outlet in the incineration mode than in the pyrolysis mode. Sulfur trioxide concentrations in afterburner inlet and outlet were similar in both modes. Minor amounts of mercaptans (0 to 0.67 ppm) were found in the pyrolysis gas. Nitrogen oxide concentration was observed to increase in the afterburner. Greater NO emissions were found during the pyrolysis mode, but solids loadings to the furnace were also greater during the pyrolysis mode.

During the Concord test, mean concentrations (ppm dry weight basis) of beryllium (Be), cadmium (Cd), mercury (Hg) and lead (Pb) were determined in 7 samples of blended sludge and refuse derived fuel (RDF) and 12 samples of furnace ash, as well as separate samples in sludge and RDF (Brown and Caldwell 1977). Lead and beryllium concentrations were greater in the ash than in the blended feed. The Cd concentration was slightly less in the ash, perhaps indicating some vaporization. The Hg concentration was significantly less in the ash. To the extent that maximum furnace temperatures in the pyrolysis mode are 100°F to 200°F less than in the incineration mode, there may be slightly less vaporization of heavy metals during pyrolysis.

Residuals Disposal

Scrubber Water

The particulate matter collected in scrubber water following pyrolysis would be similar to that collected from incineration off-gases. Treatment and disposal options for scrubber water would be similar to those mentioned previously.

Ash Disposal

Pyrolysis ash or char would contain the noncombustible mineral ash plus the "fixed carbon," that is, the carbonaceous portion of the dry sludge solids that did not volatilize in the furnace. The fixed carbon is estimated as 4 to 5% of the input combustible matter in the pyrolysis mode for the 100% sludge feed situation without RDF (Foy 1977). The fixed carbon content of the char should not greatly alter the suitability of the char for landfill.

The reduced potential for complete oxidation of metals to metal oxides in a pyrolysis furnace could result in an ash with different leaching characteristics than incinerator ash. The recent sludge management planning study for the New York-New Jersey metropolitan area cited a 1975 study by Majima and others that indicated the reducing atmosphere in a pyrolysis furnace would decrease the leachability of chromium by preventing the oxidation of insoluble trivalent chromium to soluble hexavalent form (Camp, Dresser and McKee and Potter 1976). The initial state of the metal is obviously important. The 1973 H&E study found chromium to be less soluble after incineration.

Pyrolysis would not appear to alter greatly the suitability of furnace ash for landfill. The questions regarding leachability and permanence of landfill barriers, as discussed for incineration, still remain.

Impact of Sludge Management Issues

The comments made previously about incineration concerning the adaptability to secondary sludge, the impact of industrial pretreatment and the sensitivity to transportation costs also apply to pyrolysis of sludge in multiple-hearth furnaces.

2.3.3 Coincineration/Copyrolysis

Description of Process

Municipalities are often confronted with increasing quantities of municipal solid waste and sewage sludge and decreasing availability of landfill areas. Solid waste and sewage sludge have been incinerated for many years. Solid waste generally has sufficient heat value to burn without auxiliary fuel, except for start-up or temperature control. Sewage sludge often requires auxiliary fuel when it is incinerated, except in newly designed and optimized situations discussed previously. The coincineration of solid waste and sewage sludge has certain advantages, mainly the use of solid waste to provide the required auxiliary heat value for incineration of sludge.

The major questions of technical feasibility have been concerned with the proper methods of introducing the two different feed streams into the furnace and proper furnace design. Operating problems that have affected many attempts at coincineration appear related to unsuccessful modifications of existing solid waste incinerators. For example, grates that are adequate for support of solid waste during combustion can be unsuitable for semiliquid sewage sludge.

There are many different furnace configurations that have been attempted or are being investigated for coincineration. A detailed investigation of alternative coincineration processes was prepared by Roy F. Weston, Inc., in 1976 for the EPA Municipal Environmental Research Laboratory titled A Review of Techniques for Incineration of Sewage Sludge with Solid Waste. This study presents theoretical heat and material balances for various technologies and includes summary descriptions of existing coincineration plants in this country and Europe.

For this case study, the main reference for coincineration of MDC's sewage sludge is a report completed in 1976 by Stone and Webster Management Consultant, Inc. for the MDC entitled The Commonwealth of Massachusetts Metropolitan District Commission, Boston Metropolitan Area Waste Treatment Feasibility Study. This study was commissioned by MDC at the request of Region I EPA to supplement the Draft EIS and for inclusion in the Final EIS on the proposed MDC Phase I sludge management plan (Shaugnessy 1977b). Coincineration was not considered in the 1973 H&E report.

The following description of coincineration facilities is based on the recommendations of the Stone and Webster report, which did not present a site-specific comparison of alternative coincineration technologies, but instead used the technology recommended in the Roy F.

Weston report as the most economical system. For this study, an emerging copyrolysis technology based on the multiple-hearth furnace was also selected for evaluation. Both technologies are described below.

Coincineration

The Stone and Webster report recommended construction of coincineration facilities at the site of the abandoned City of Boston incinerators as the most feasible coincineration option. In August 1975, the existing City of Boston "South Bay" incinerator located on South Bay Avenue near the junction of the Pulaski Skyway and Fitzgerald Expressway was closed by court order because of air pollution problems. The City of Boston is proposing to build a new solid waste incinerator on the same site with production of byproduct steam for sale to the Boston Edison Company, which has a steam transmission main approximately 2,000 feet from the South Bay site.

Stone and Webster estimated that 1,500 tons per day of solid waste would be available from the Boston area in 1985, after making allowance for existing solid waste handling capacity in the area. Therefore, the solid-waste-to-sludge-solid ratio in 1985 would be 1,500/127.5 or about 12 to 1. The Roy F. Weston report (1976) recommended that the solid-waste-to-sludge-solid ratio be at least 10 to 1.

The coincineration option recommended by Stone and Webster for the South Bay site included two water-walled boilers, each designed for 750 tons per day of raw solid waste plus 92 tons per day of dry sludge at 70% solids. Each boiler would be capable of producing 185,000 pounds per hour of saturated steam at 250 psi. These water-walled boilers would be of the mass fired type with a front-end raw solid waste chute entrance at the high end of the grate system.

Dewatered sludge at 30% solids would be barged in containerized trailers from Deer and Nut Islands to Wiggins Terminal and trucked approximately 3 miles to the South Bay site. At South Bay, the sludge would be dried to at least 70% solids in a direct contact rotary dryer. Heat for the dryer would be provided by a fraction of the hot stack gases that would pass through the dryer and then be returned to the furnace below the grates for deodorization. The dried sludge would be blown into the top of the combustion zone with combustion of the sludge occurring in suspension.

Exhaust gas from the boilers would pass through an electrostatic precipitator for particulate removal. The ash handling system would be "dry," in which the ash is spray-quenched rather than dropped into a water pit. Ferrous metals would be recovered from the ash by magnetic separators.

Copyrolysis

The copyrolysis in the multiple-hearth furnaces considered here is essentially the same process as that tested by Brown and Caldwell (1977) and Envirotech in Concord, CA. Because a multiple-hearth furnace is used, the solid waste must be shredded and classified before introduction to the furnace. Although shredding and classification is required, some cost can be offset by greater resource recovery, including ferrous scrap uncontaminated by the combustion/melt down process, aluminum and, perhaps, glass. A front-end waste classification plant for production of RDF would consist of the following processes:

- primary shredder,
- air classifiers,
- magnetic separation,
- aluminum separation and
- secondary shredders.

RDF is essentially the combustible fraction of the solid waste. Two or three day's storage would also be required to ensure a continuous RDF supply even during maintenance or repair of the front-end plant.

The pyrolyzing multiple-hearth furnace would be the same as that discussed previously except additional feed equipment for RDF would be required. Sludge would be fed in at the upper hearth, and RDF would be fed to a mid-furnace hearth. Furnaces, duct work, fans and air pollution control equipment would be sized appropriately. For the South Bay site, where wastewater treatment plant effluent would not be available for scrubber water, an electrostatic precipitator would be used.

In the case of copyrolysis in multiple-hearth furnaces, separate sludge drying would not be required. Sludge drying would occur on upper hearths as in a conventional multiple-hearth incinerator. However, in this process, cake dryness is less critical because of the general abundance of RDF, which would serve as the auxiliary fuel. Of course, maximum cake dryness would contribute to increased waste heat recovery.

For the projected 1985 conditions of 1,500 tons per day of solid waste and 127.5 tons per day of dry sludge solids, three 25 ft-9 in. diameter eight-hearth furnaces would be required. It was assumed, based on experience at the Concord, CA copyrolysis facility, that 60% of the solid waste would be RDF.

Review of Local Studies

The 1973 H&E study did not include coincineration as an alternative sludge management plan. The Draft EIS mentions coincineration but indicates it does not appear practicable for the Boston area. After some internal debate prompted by the Solid Waste Section, Region I EPA decided to require that MDC prepare a more detailed feasibility study of coincineration in Boston for inclusion in the Final EIS (Leighton 1977). A suggested scope of work was prepared by Region I EPA and supplied to the MDC.

The MDC hired Stone and Webster to prepare the coincineration feasibility study, which was completed in November 1976. EPA had review privileges, and EPA staff members were present at project review meetings with MDC and Stone and Webster (Forzley 1977).

The 1976 Stone and Webster report recommended mass-fired water-walled boilers with a rotary dryer for sludge predrying as the optimal method for coincineration at the proposed City of Boston incinerator at South Bay Avenue. The recommended process is discussed in the preceding section, and its operation is discussed in the following section.

The cost information presented in the 1976 Stone and Webster report were June 1976 costs, Engineering News Record cost index of 2410 (Forzley 1977). The total project capital cost for the coincineration alternative described above, including separate vacuum filtration facilities for sludge dewatering at Deer and Nut Islands, was estimated to be $53,381,000 (ENR 2410), based on public ownership, but private operation of facilities at South Bay. The net annual operating cost allowing for steam revenue and ferrous metal recovery was $6,244,000. The capital cost was amortized over a 25-year period based on a semiannual interest payment at 7%. The net annual cost would be recovered from the City of Boston, the MDC and the industrial and commercial sector as waste tipping fees.

The Stone and Webster report (1976) also presented capital and annual costs for similar facilities at South Bay handling only 1,500 tons per day of solid waste without sludge dewatering, predrying or combustion. The total project capital cost for independent solid waste incineration was $39,555,000 (ENR 2410) with a net annual cost of $2,409,000 to the City of Boston and industrial and commercial users.

Ignoring the availability of grant funds, the Stone and Webster report found city-owned coincineration facilities at South Bay to have a lower total annual cost than the combined total annual costs of separate sludge and solid waste incineration. However, when the availability of state and federal grants for water pollution control facilities are considered, separate sludge incineration at Deer Island results in the lowest annual cost to the MDC. The Stone and Webster report summarized the situation as follows:

> In conclusion, cotreatment of solid waste and sewage sludge is both technically and environmentally feasible. In Boston, cotreatment is not economically feasible compared with separate waste disposal facilities. This is due to costs associated with transportation of sludge from Deer and Nut Islands to South Bay and the federal and state capital grant structure, which supports water pollution control facilities but not solid waste control facilities. The most economical sludge disposal method for MDC is sludge monotreatment at Deer Island taking advantage of full capital grants. If cotreatment of solid waste and sludge were to be instituted, cotreatment at Deer Island would be the more economical site for MDC, while South Bay is the more economical site for Boston.

Energy Considerations

As stated previously, the advantage of coincineration is that auxiliary fuel is not required, except for start-ups. The following discussion considers other operating costs and the potential for waste heat recovery.

Table 2.3-13 presents a summary of the unit process operation and maintenance costs for coincineration, copyrolysis and independent solid waste incineration as cases C_1, C_2 and C_3, respectively. The water consumption shown in Table 2.3-13 is for steam sold to Boston Edison, the cost of which would be recovered in water-back charges discussed later.

The manpower requirements for operation of the coincineration and independent solid waste facilities were taken from the 1976 Stone and Webster report. It was assumed that the full-time manpower required for operation of copyrolysis facilities would be equivalent to the coincineration case. The Stone and Webster report (1976) estimated that the manpower would include 10 management personnel plus 65 operating staff, covering plant operations, maintenance and receiving. Although Stone and Webster showed no auxiliary fuel requirements, it was assumed that a minimal amount of start-up fuel would be required.

The electrical energy consumption rates shown for coincineration and independent solid waste incineration were taken from Stone and Webster and were verified by comparison with power consumption rates for similar situations presented in the Roy F. Weston coincineration study. The electric power consumption shown for the copyrolysis facility is composed of power requirements for the multiple-hearth furnace and the front-end plant for RDF production. The power requirement for the multiple-hearth furnaces without high energy scrubbers was assumed to be 20 Kw-hr per wet ton input. The power requirement for the RDF front-end plant with primary and secondary shredders, separators and air classifiers was taken to be 50 Kw-hr per ton solid waste input based on similar estimates for the Concord, CA study (Brown and Caldwell 1977).

Annual maintenance costs were based on 2% of the capital cost of furnace and steam generation facilities as shown in Appendix 3A, except for the RDF front-end plant. The RDF front-end plant was assumed to require significantly greater maintenance than other facilities, and the annual maintenance cost for the front-end plant was assumed to be 5% of the plant's capital cost as was estimated in the Roy F. Weston study for similar facilities (Weston 1977). The annual O&M costs associated with the RDF front-end plant represent a major uncertainty in the novel

TABLE 2.3-13

SUMMARY OF UNIT PROCESS O&M COSTS

(codisposal cases)

Variable	C_1 Coincineration	C_2 Copyrolysis	C_3 Independent Solid Waste Incineration
Labor			
manhours/day	427	427	399
manhours/yr	155,855	155,855	146,635
Energy			
electric			
Kw-hr/day	36,000	113,500	33,200
Kw-hr/yr	1.314×10^7	4.143×10^7	1.212×10^7
Start-up fuel oil			
gal/day	60	60	60
gal/yr	2.19×10^4	2.19×10^4	2.19×10^4
Water			
gal/day	8.01×10^5	7.12×10^5	7.55×10^5
gal/yr	2.93×10^8	2.60×10^8	2.76×10^8
Annual Costs			
Labor @ \$6.84/manhour	\$1,066,000	\$1,066,000	\$1,003,000
Electric @ \$0.03/Kw-hr	395,000	1,243,000	364,000
Fuel oil @ \$0.38/gal	8,000	8,000	8,000
Water @ \$0.50/1,000 gal	146,000	130,000	138,000
Maintenance @ 2%*	822,000	1,963,000**	722,000
Total O&M \$/yr	\$2,437,000	\$3,410,000	\$2,235,000
Gross Unit O&M Cost*** \$/wet ton input	\$3.46	\$4.85	\$4.08

*Maintenance cost based on 2% of capital cost of combustion and steam generation facilities only.

**Includes maintenance taken at 5% of RDF processing plant capital cost.

***Basis: solid waste input at 1500 wet tons/day and sludge cake input at 427 wet tons/day @ 30% solids.

copyrolysis technology, and more detailed consideration of these costs could lead to lower estimates.

Table 2.3-14 presents a summary of the potential revenues from resource recovery at the South Bay facility. The major source of revenue would be steam sales to Boston Edison. The steam production rates for the coincineration and independent solid waste incineration were taken from Stone and Webster. Stone and Webster projected average steam production for sale to Boston Edison to be 371,000 lbs per hour for coincineration and 350,000 lbs per hour for independent solid waste incineration, both saturated steam at 250°F. These quantities were apparently based on a unit steam production rate of approximately 3 lbs/ton of waste experienced at similar facilities in Harrisburg, PA and not on detailed heat balances.

For copyrolysis, computer heat balances indicated that a temperature of 2,585°F could be attained in the afterburner when pyrolysis gas was burned. For a temperature drop of 2,585°F to 450°F in a waste heat boiler, approximately 330,000 lbs per hour of saturated steam at 250°F could be produced, although higher pressure and temperature steam could be produced. Considering that the steam production for the coincineration case was determined from a rule-of-thumb estimate, it is not clear that the coincineration process should offer greater thermal efficiency than the pyrolysis process. Also, the Stone and Webster report does not state the fraction of heat available in the stack gases, which must be used in the sludge predryer instead of for steam production.

The Stone and Webster report estimated that approximately 105 tons per day of ferrous metal scrap could be recovered from the 1,500 tons per day of refuse feed. The major uncertainty is the price that will be paid for the scrap. The ferrous scrap market is unstable, with prices, according to Stone and Webster, sometimes being set prohibitively low by steel mills. Furthermore, the price for steel scrap separated ahead of incineration, thereby avoiding contamination with metals such as tin, may also be greater than the price paid for ferrous metal separated from ash. Stone and Webster indicated that current prices for steel scrap in Boston were about $50 per ton FOB. For the purposes of this study, the net 1975 price for scrap steel was assumed to be $20 per ton after transportation.

TABLE 2.3-14

POTENTIAL RESOURCE RECOVERY AT CODISPOSAL FACILITIES

Variable	C_1 Coincineration	C_2 Copyrolysis	C_3 Independent Solid Waste Incineration
Steam production (sat. 250°F) - lbs/hr	371,000	330,000	350,000
@ $2/1,000 lbs @ 75% use, $/yr	$4,875,000	$4,336,000	$4,599,000
Ferrous metal sales - tons/day	105	105	105
@ $20/ton net, $/yr	$766,000	$776,000	$766,000
Aluminum sales - tons/day	0	7.5	0
@ $280/ton net, $/yr	0	$766,000	0
Water-back charges - $/yr	$146,000	$130,000	$138,000
Annual revenue, $/yr	$5,787,000	$5,998,000	$5,503,000

Region I EPA staff estimated that the aluminum content of New England solid waste was 0.5% by weight, which is slightly less than the national average of roughly 0.75% (Leighton 1977). The front-end plant required for RDF production in the pyrolysis case would be capable of collecting approximately 7.5 tons of aluminum per day. The current price for scrap aluminum in the Boston area is $340 per ton F.O.B. A net 1975 price of $280 per ton was used.

The water-back charges shown in Table 2.3-14 reflect the boiler water consumption at $0.50/1,000 gallons, which would be collected from Boston Edison. The unit process O&M costs and projected revenues in Tables 2.3-12 and 2.3-13 will be incorporated into total system alternatives developed in Section 3.

Air Quality Considerations

Applicable Standards

The EPA NSPS for municipal incinerators (less than 50 tons per day) is a maximum particulate concentration of 0.08 grains per dry standard cubic foot corrected to 12% CO_2 in the stack gases (39FR20790). Massachusetts has a stricter emission limit of 0.05 grains per dry standard cubic foot (dscf) at similar conditions. There are no federal or state standards that set specific emission limits for SO_2, CO, NO_x or hydrocarbons from refuse incinerators. Also, it is unknown if the federal standard that limits mercury emissions to 3,200 grams per day from sewage sludge incinerators may be considered applicable to coincineration/copyrolysis facilities.

The federal emission offset policy for new sources locating in nonattainment areas, as described previously for sludge incineration, may be the most significant air pollution control requirement affecting implementation of a coincineration/copyrolysis facility on South Bay Avenue in Boston. Conversations with Region I EPA staff indicated that consideration had been given to accepting the closure of the old City of Boston incinerator as a particulate emission offset for new coincineration facilities at the same site (Leighton 1977). Region I EPA staff was trying to decide, in general, how long ago a source could have been shut down and still be claimed as a credit. Any such decision would have required approval from EPA headquarters in Washington. However, the new Clean Air Act Amendments stipulate that "emission offset banking," that is, claiming offsets for past emission reductions, is not allowed for such previous reductions that occur more than one year before permit application by the new source. Also, the new Clean Air Act Amendments contain no special exemptions for state-owned facilities (Leighton 1977); however, resource recovery projects burning municipal solid waste may be exempted from offset regulations.

Projected Emissions

The 1976 Stone and Webster report estimated emissions from the coincineration facility as shown in Table 2.3-15. This report indicated that the particulate emission rate could be achieved using electrostatic precipitators (one for each boiler) operating at 99.2% removal, based on an inlet loading of 6.25 grains/dscf. The precipitators would have no effect on the gaseous pollutants shown in Table 2.3-13. The coincineration facility would be a new "major" source of particulates, SO_2, NO_2 and hydrocarbons according to EPA criteria. Emission offsets for particulates and hydrocarbons may be necessary.

Pyrolysis of RDF and sewage sludge in multiple-hearth furnaces should theoretically result in lower particulate entrainment in furnace exhaust gases because of the low air flow rates through the furnace. Also, the extremely high temperatures in the afterburners should contribute to lower particulate loadings. Compliance with the Massachusetts standard of 0.05 grains/dscf should also be possible with the copyrolysis facility. The particulate emission rate shown in Table 2.3-15 can be considered applicable to the copyrolysis case, realizing that even lower particulate emissions may be possible.

The use of afterburners in the pyrolysis facility should reduce CO and hydrocarbon emissions to negligible levels. The copyrolysis tests at Concord, CA indicated that the SO_2 emissions during pyrolysis may be less than those resulting from incineration. The limited oxygen available in the furnace during pyrolysis apparently prevents complete oxidation of sulfur to SO_2. The data are insufficient to estimate how NO_2 emissions might change in the pyrolysis mode. Particulate emission

TABLE 2.3-15

PROJECTED EMISSIONS FROM COINCINERATION

Pollutant	Emission Factor	Emission Rate (lb/hr)	Emission Rate (tons/yr)
Particulates (grains/dry standard cubic foot)	0.05	67.5	296
Sulfur dioxide (% S in feed solids)	0.1*	270	1,183
Nitrogen dioxide (ppm by volume)	150**	246	1,077
Carbon monoxide (ppm by volume)	150**	150	657
Hydrochloric acid (ppm by volume)	400**	514	2,251
Hydrocarbons (lb/ton of solids input)	1.5†	100	438

Basis: 1,500 tons per day of solid waste plus 128 dry tons per day of sludge solids (1985 conditions).

*SO_2 emission rate calculated based on 100% conversion of S to SO_2 with 0.1% S in solids by weight.

**From Northeastern Massachusetts Resource Recovery Project - Draft EIR.

†From EPA Compilation of Air Pollutant Emission Factors.

Source: Stone and Webster 1976.

offsets may be required for copyrolysis, but afterburner operation should eliminate the need for hydrocarbon offsets.

The Stone and Webster report states that the coincineration facility would not exceed the sludge incinerator mercury emission limit of 3,200 grams per day; however, this statement is undocumented in the report. Overall emissions, either gaseous or particulate, from the copyrolysis facility should be less than similar emissions from coincineration because the bulk of the metals are separated during RDF production.

Residuals Disposal

The Stone and Webster report assumed that fly ash collected in the electrostatic precipitators and the bottom ash would be trucked to a landfill at Plainville. There would be no scrubber water at the South Bay site. Stone and Webster estimated that 30 to 50 gallons per minute (gpm) of ash quench water would be required, but presumably in the "dry" quench process specified most of this water would be vaporized. The potential for metal leaching from ash produced during coincineration should be subject to the same uncertainties discussed for sewage sludge incinerators, only the daily metal loading to a landfill is, of course, greater when solid waste is also incinerated.

In the copyrolysis case, most of the metals, glass and other heavy objects are separated in the RDF plant ahead of incineration. Any of these materials that cannot be sold as scrap would also be used as landfill.

Impact of Sludge Management Issues

Secondary Sludge Considerations

The coincineration/copyrolysis facilities described above are sized to handle 1,500 tons per day of solid waste and the projected 1985 digested primary sludge quantities from Deer and Nut Islands (127.5 dry tons per day).

For the coincineration alternative, Stone and Webster indicated that one more water-walled boiler at the South Bay site would be required to handle 1995 sludge quantities including secondary sludge solids. The Stone and Webster report also indicated that the quantity of solid waste that would be available for coincineration at South Bay in 1995 would be approximately 2,250 tons per day. The solid-waste-to-sludge solids ratio in 1995 would be less than 10:1, which would be lower than recommended in the Stone and Webster report and in the recent Roy F. Weston study for such coincineration facilities (Weston 1976). Stone and Webster estimated that auxiliary fuel would be required to compensate for the difference in heat input because of the deficiency of solid waste, but fuel requirements were not quantified.

For the copyrolysis alternative, additional multiple-hearth furnace capacity would be required for increased 1995 sludge quantities. The copyrolysis tests conducted in Concord, CA found that the RDF-to-sludge solids ratio for autogenous operation of the multiple-hearth furnace copyrolysis system could be as low as approximately 1 to 1 on a wet basis (Brown and Caldwell 1977). This is also a solid waste to dry sludge ratio of roughly 10 to 1 on a dry weight basis (assuming 17% solids in sludge cake and 0.6 lb RDF per lb solid waste as typical of the Concord tests).

Sludge Pretreatment

In the coincineration case, the bulk of the metal input to the boilers would presumably come from the solid waste fuel. Thus, pretreatment to reduce metal input to the sludge would reduce the metal content of the emissions and residue from the coincineration facility, but such reduction may not be a significant fraction of the total metal input to the boilers.

In the copyrolysis process, the bulk of the metals in the solid waste stream are separated in the RDF plant. However, the Concord study still found the concentrations (dry weight basis) of most metals in the RDF to be comparable to the concentrations found in the sludge. Average mercury concentrations in the RDF used in the Concord, CA tests from two different sources ranged from approximately 2 ppm to 4.5 ppm on a dry weight basis (Brown and Caldwell 1977). The average mercury concentration on a mass-weighted basis for blended Deer and Nut Islands digested primary sludge was 6.8 ppm for 1973 to 1977.

Transportation Costs

For the coincineration/copyrolysis options, the transportation of sludge to South Bay becomes a significant cost. The Stone and Webster report concluded that transporting sludge to the South Bay site was cheaper than transporting solid waste to Deer Island and removing ash from Deer Island. Therefore, it was recommended that coincineration be conducted at the South Bay site with dewatered sludge (30% solids) barged separately from Deer and Nut Islands in containers to Wiggins terminal and then trucked to the South Bay site. Estimated costs for the transportation of sludge to South Bay are presented in Appendix 3A, where total system alternatives are developed. Stone and Webster also found that it would be less expensive to barge sludge from both islands than it would be to build a sludge pipeline from Nut Island to Deer Island and then transport dewatered sludge from Deer Island only. Thus, in general, close proximity of sewage treatment and coincineration facilities would be the most desirable situation.

Federal Funding

There are presently no federal funds for construction of solid waste incinerators (Leighton 1977), because the Resource Conservation and Recovery Act of 1976 did not allocate construction funds. EPA does hope to promote coincineration through technology transfer and technical aid to local planners (Leighton 1977).

Presumably, Clean Water Grant funds would be available for 75% of the capital cost of sludge dewatering and transport facilities required to get the sludge to the coincineration/copyrolysis plant. The rotary sludge dryer required for coincineration should also be fully eligible for grants, if publicly owned. Presumably, Clean Water Grant funds would be available on a prorated basis for a share of the capital cost of furnaces/boilers and associated equipment, if such equipment is publicly owned, such as by the City of Boston. The RDF front-end plant required for copyrolysis would probably not be eligible for grants since it is solely used for solid waste processing.

If the facility at South Bay is privately owned and operated, no grant funds would be available for the facilities at that site.

2.4 Land Alternatives

This section evaluates land-oriented sludge management alternatives and applies them to the Boston Case Study. A review of local and national sludge management experience is included to facilitate the formulation of alternative cost-effective systems.

Sludge management alternatives associated with land include: use of liquid, dewatered, composted or dried sludge applied at relatively low application rates for agricultural or landscape purposes; reclamation of nonproductive lands with high rate application of liquid or dewatered sludge and disposal of sludge in a liquid, dewatered cake or ash form in a sanitary landfill.

2.4.1 Sludge Utilization

Because of stringent and changing air quality requirements, escalating costs of fuel and fertilizers and increasing environmental constraints regarding sanitary landfill procedures, increasing attention is being given to use of sludge for agricultural purposes. In Section 201 of PL 95-217, federal agencies must encourage waste treatment management techniques that could result in the construction of revenue-producing facilities providing for recycling of potential pollutants through the production of agriculture, silviculture or aquaculture products. In Section 4001 of PL 94-580 (Resource Conservation and Recovery Act of 1976) state and regional solid waste plans are encouraged to "maximize the utilization of valuable resources and to encourage conservation."

Description of Process

The process employs the application of sludge in either liquid (approximately 5% solids) or dewatered (20 to 30% solids) form on agricultural land. Using proper farm management procedures, the sludge can provide the total nitrogen, phosphorus and micronutrient requirements of the product crop. The prime mechanisms for sludge use are soil filtration, uptake by plants, immobilization of dissolved solids by clay fractions and stabilization of sludge organics by soil microorganisms. The unit processes included in a complete sludge utilization facility are stabilization, dewatering (optional), transport, storage and application. In designing land application systems, numerous unit process suboptions are available. A critical evaluation of the technical and economic trade-offs inherent with the selection of unit processes provides a basis for the generation of cost-effective system designs.

Liquid Versus Dewatered Sludge

The use of liquid (5% solids) or dewatered (20 to 30% solids) sludge must include consideration of distance to application site, available sludge transport modes, application methods, system costs and environmental and public health considerations. Liquid sludges can be transported long distances by pipelines and readily stored in lagoons, and they are easily applied to agricultural lands. Maximum use of nutrients is also associated with subsurface injection of liquid sludge. Subsurface injection also minimizes potential environmental problems associated with odor generation, surface runoff controls and aerosol formation.

Dewatered sludge can be readily transported by tank trucks or barges. Chemical conditioning with lime stabilizes the sludge and reduces the chemical requirements for pH control of the acid soils generally found throughout Massachusetts. Using lime to control soil pH also minimizes potential plant toxicity problems associated with the uptake of heavy metals. Although dewatering greatly reduces the volume of material to be handled, it may not reduce total system costs because of the high process costs of dewatering itself.

Because the issue of liquid vs. dewatered sludge has a direct effect on the technical and economic design of land application facilities, both alternatives should be considered. Such an approach will provide for explicit assessment of the entire option's sensitivity to other unit processes such as transportation mode and application techniques.

Transportation/Storage

Liquid sludge can be transported by pipelines, railroad tank cars, barges or tank trucks. For large metropolitan areas such as Boston, where suitable application sites are far from the service area, pipeline or unit train transport of liquid sludge is the most cost-effective system. However, the initial investment required for pipeline construction requires a long-term commitment of a particular area to the agricultural use of sludge. Furthermore, if application sites are widely dispersed, then these transport modes may not prove cost effective. The most flexible and expensive transport system is tank truck. To be cost effective, considering the large transport distances involved with this study, truck transport of sludge would require sludge dewatering.

Liquid sludge can be more readily stored and applied to the land through the use of dredge equipment and pipeline transmission mains to sludge application sites or through the use of self-load tank truck applicators. Liquid sludge storage can be provided by economical lagoons designed with an impervious lining to prevent potential groundwater contamination. On the other hand, storage of dewatered sludge requires more expensive facilities to protect the dewatered sludge from the elements, thereby protecting nearby surface and groundwater resources. Handling dewatered sludge also requires expensive equipment such as front-end loaders.

Sludge Stabilization

The predominant sludge stabilization technique practiced in the United States is sludge digestion. Anaerobic digestion is currently practiced at both the Deer and Nut Islands plants. Because of the investment in these facilities, their energy efficient operation associated with methane generation and reuse and the high energy costs associated with aerobic sludge digestion, continued anaerobic sludge digestion has been viewed as the sludge stabilization technique for the Phase I primary sludge facilities (EcolSciences 1976).

However, anaerobic digestion of sludge does not completely destroy pathogens or viruses. Sludge can be stabilized by other techniques such as using lime to produce a high pH (11 to 12), composting sludge in the 55 to 65°C range, using heat to dry the sludge, pasteurizing the sludge at 70°C for 30 to 60 minutes and using such emerging technologies as irradiation. These additional measures for increasing sludge stabilization before land application are generally not practiced because of increased system costs. Current land application systems in the United States generally use sludge digestion facilities as the sludge stabilization process, together with environmentally acceptable application methods to minimize potential adverse public health concerns associated with bacterial or viral disease transmission.

Application Techniques

Liquid sludges can be applied to agricultural lands through a number of techniques, including self-loading or top loading liquid manure wagons and truck mounted tanks with high flotation tires that minimize soil compaction problems and provide for system operation under wet soil conditions. Attachments are available for surface injection of the sludge.

Liquid sludge can also be applied using equipment supplied by a pipeline. Pipeline and hose supply units for sludge application include traveling tool bar injectors or heavy offset agricultural disks, which require large crawler type or four-wheel drive tractors pulling 600 feet of four to five-inch flexible supply hose. A traveling or stationary high pressure irrigation gun is another piece of application equipment supplied by a pipeline. Another surface application technique for liquid sludge is the use of ridge and furrow or gated pipe irrigation systems. For dewatered sludges, spreaders for dry manure are generally used for surface application. Subsurface injection techniques have the inherent advantage of providing odor and runoff controls together with maximizing the use of sludge nutrients. However, a disadvantage of such systems is that they generally cannot be used during the growing season.

Tank truck applicators provide the greatest system flexibility, especially if application sites are dispersed. The use of equipment supplied by a pipeline is generally more appropriate for large dedicated tracts of land, thereby requiring a more long-term commitment of the site for sludge application.

Site Selection

To eliminate the high land costs associated with publicly-owned facilities, the use of privately owned dispersed sites east of the Connecticut River can be considered. A review of these sites indicated a grouping pattern of five regions (see Figure 2.2-3, Major Transportation Corridors in Section 2.2.3) that could be readily supplied by a pipeline transport system. Liquid sludge could be pumped to one of five regional systems. Six-month liquid sludge storage could be developed at large regional (20 million gallon) lagoon facilities on dedicated tracts of land or on-site at a number of the dispersed application sites requiring approximately 2% of the net irrigible area for storage purposes. To provide system flexibility with this dispersed site system, large 6,000 gallon tanks trucks would be required to distribute sludge from the storage facilities to the application site. Subsurface sludge application could be accomplished using 2,000 gallon tank truck applicators that could directly self-load from the 6,000 gallon distribution trucks.

The use of these subsurface tank truck applicators would minimize buffer requirements, provide for maximum use of nutrients and minimize odor and runoff problems. Although sludge could not be applied during the growing season, different crop plantings could be staged such that a 60 to 120 day application period could be possible.

Based on an annual loading rate of 10 dry tons per acre, approximately 4,400 net acres would be irrigated, representing approximately 18% of the land available in the area (EcolSciences 1976). The initial costs of the sludge pipeline could be offset by staged construction to the regional systems. However, the construction of the pipeline does represent a long-term commitment towards the agricultural use of the sludge.

A centralized publicly-owned land application facility must also be considered. Past reports (EMMA Volume 5 [M&E 1976]) have identified significant quantities of forested and open lands suitable for sludge or wastewater use in the Plymouth/Sandwich area. A sludge pipeline transport system could economically service this area. Forested lands could be cleared with the pulp marketed to nearby paper industries. The use of large MDC-operated and monitored sites might enable increased sludge application rates, thereby decreasing land requirements and system costs. Subsurface sludge application could be made using economical techniques such as tractor/plow application supplied by buried pipelines and flexible hoses as is practiced by the MSD in Chicago.

A publicly-owned facility may also consider land application of dewatered sludge. Dewatered sludge would be barged from the Deer and Nut Island plants to the Sandwich terminal for truck transport to the MDC-owned sites. Dewatered storage facilities would be provided on-site. Application of sludge would be accomplished by manure spreaders. An inherent advantage of this plan is that the lime content of the sludge provides for favorable soil pH conditions. However, this feature must be analyzed in the context of increased costs associated with dewatering, barge transport and sludge handling equipment.

Review of Local Studies

In June 1973, H&E presented the MDC with an alternative sludge management plan for the Deer and Nut Islands sewage treatment plants. Two land application systems that incorporated both primary and secondary sludge management were studied to meet the 1995 sludge conditions. The preferred land application system included pipeline transport of 5% sludge to MDC-owned land totalling 35,000 acres (20,900 net irrigated acres). Annual application rates of 5.62 dry tons per acre were used based on a nitrogen balance analysis over a 7-month application period. Liquid sludge storage over a 5-month period was provided. Pasteurization of the digested sludge at the treatment plant before transport was also provided. The selected sludge application technique was the high pressure traveling spray gun.

The second system included pipeline transport of pasteurized digested liquid sludge to dewatering facilities followed by rail transport, storage and vehicle transport to land application or landfill sites.

In 1976, the Draft EIS on the proposed sludge management plan for the MDC was prepared for the EPA Region I by EcolSciences, Inc. A land application system was formulated in this study to manage the 1985 primary sludge conditions at the Deer and Nut Islands plants. The Draft EIS land application system involved the use of privately-owned cropland dispersed throughout the state because of possible difficulties in effecting an MDC-owned system, which requires large tracts of farmland to be taken out of the private business sector and, thus, commits the use of such land on a long-term basis for sludge application*. Sixty sites totaling 55,000 acres were identified as suitable for land application.

Because of the scattered location of these sites, truck transport of dewatered sludge to approximately five regional sludge storage facilities was deemed necessary. Digested sludge from Nut Island was pumped to Deer Island for dewatering, then barged to Mystic Terminal before transport by truck to application sites, an average one-way haul distance of 70 miles.

Application rates of 5 to 10 dry tons per acre were used based on nitrogen loading requirements for a corn crop. Six-month sludge storage was provided. Manure spreading equipment requirements were based on a 60-day annual application period. Because of the high cadmium to zinc ratio found in Boston sludge, another land application alternative assumed that 50% of the total sludge with acceptable metal contents would be applied to the land, while the remainder would be hauled by truck to the Plainville landfill site.

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*The assumption, presented in the Draft EIS, that an MDC-owned facility would involve such difficulties as to require its elimination as an alternative was not elaborated.

Review of Other Studies

The applicability of sludge utilization systems is increasingly being considered and, in many cases, implemented in large urban areas throughout the United States. Philadelphia is under orders by the EPA to eliminate ocean disposal of sludge by 1981. Currently, the city is in the developmental stage of a public give-away program of air dried sludge, a liquid land application program using tank truck applicators and a windrow composting program. Philadelphia is also studying the feasibility of strip-mine reclamation and landfill cover programs using their sludge.

Detroit's metropolitan service area currently generates 70 dry tons per day of sludge. Approximately half this amount is dewatered and incinerated with ash landfill at sites 30 to 40 miles from their treatment facility. The remaining sludge is discharged into the Detroit River. Recently plans were completed for installation of additional dewatering and incinerator facilities. Bids were advertised, but cancelled because of Detroit's increasing supplemental fuel cost for incineration. Detroit is currently investigating alternative energy efficient management systems including composting and land application (Devenzo 1977).

In Chicago, the MSD operates an extensive sludge utilization program (MSD 1976). Between 1974 and 1976, their sludge management program distributed an average of 740 dry tons per day. Of this amount, approximately 52% was used as a liquid fertilizer on agricultural land. The majority of the liquid sludge was hauled 140 miles by barge to MSD-owned facilities. In 1976, application of sludge (5% solids) was made to over 2,500 acres of cropland between April 29 and October 29. Application rates ranged from 6 to 60 dry tons per acre. Application methods included spray and gated pipe irrigation and subsurface plow injection. Twenty percent of the MSD sludge was heat dried and sold as a fertilizer at an average price of $17.50 per ton. During 1974 to 1976, the remaining 28% of the sludge (211 dry tons per day) was air dried, digested Imhoff sludge. This sludge, with a solids content of 50 to 60%, was distributed free throughout the MSD service area under the name "Nu Earth." Thousands of brochures describing Nu Earth, its use and where to get it were distributed to area gardeners at the annual Flower and Garden Show and at several garden club meetings and community functions. The success of this program is evidenced by the fact that the demand for Nu Earth exceeded the available supply. Public pick-up points included four MSD locations and 88 municipal locations that dispersed 30% of the Nu Earth. The remaining 70% was delivered to individual users by a private trucking company under contract to the District.

Toledo, Ohio (Young 1977) currently generates 35 dry tons per day of digested filter cake. This sludge is hauled by a private contractor approximately 15 miles to numerous farmers in the area and applied at rates of approximately 6 to 8 dry tons per acre. Originally, the sludge was given to the farmers; recently they have been charged approximately $20 per acre. To date, the contractor has applied sludge on approximately 1,500 acres in the Toledo area.

Most of the federal- and state-funded studies that have examined the effects of long-range sludge application to croplands have been limited to the controlled conditions of relatively small-scale test plots. A recent EPA study (EPA 1977a) assessed the impacts of sewage sludge utilization on cropland at nine study sites under conditions of actual practice. These sites and their respective characteristics are shown in Table 2.4-1. Several important points can be seen from the information presented in Table 2.4-1. Crops grown on sludge-amended soils ranged in use from animal food (nondairy cattle) to human food, flour and alcohol). Operationally, the reported years of sludge spreading ranged from 5 to 17 years with annual application rates ranging from 16 to 16 m tons/hr. The sewage facilities, for the most part, were small to medium size and served populations ranging from 13,000 to 164,000 persons. Six out of the nine facilities served populations of 50,000 or less. Of the seven states in which the study sites were located, three (Wisconsin, Illinois and Ohio) had published guidelines

TABLE 2.4-1

COMPARISON OF PHYSICAL PARAMETERS FOR NINE STUDY SITES

Site Location	Agricultural Crop	Food Crop Use	Surface Soil Description*	Surface Soil pH**
Macon, GA	Cheatgrass	Nondairy cattle feed	Sandy loam	3.7
Las Virgenes, CA	Ryegrass	Nondairy cattle feed	Clay loam	6.5
Wilmington, OH	Alfalfa	Nondairy cattle feed	Silt loam	6.5
Springfield, MO	Fescue	Nondairy cattle feed	Silt loam	7.0
Chippewa Falls, WI	Soybeans	Open market†	Sand	5.5
Hopkinsville, KY	Fescue	Nondairy cattle feed	Silt loam	6.2
Frankfort, IN	Wheat	Flour mill	Silt loam	6.7
Kendallville, IN	Alfalfa	Nondairy cattle feed	Clay loam	6.4
Columbus, IN	Corn	Distillary	Sandy loam	6.6

*USDA Classification

**0.01 m $CaCl_2$ method

†Crop not harvested because of poor yield

TABLE 2.4-1 (Continued)

Site Location	STP Average Capacity (m^3/day)	Population Equivalent	Type of Secondary Treatment	Estimated Industrial Contribution (percent flow)
Macon, GA	45,400	125,000	Trickling filter	30
Las Virgenes, CA	17,000	75,000	Activated sludge	10
Wilmington, OH	7,600	19,000	Activated sludge	25
Springfield, MO	75,700	164,000	Activated sludge with Kraus modification	15
Chippewa Falls, WI	13,200	51,000	Activated sludge	65
Hopkinsville, KY	8,300	28,710	Trickling filter	15
Frankfort, IN	11,700	12,900	Trickling filter	30
Kendallville, IN	6,000	22,200	Trickling filter	25
Columbus, IN	24,400	50,000	Activated sludge	67

TABLE 2.4-1 (Continued)

Site Location	Reported Years of Sludge Spreading	Estimated Annual Sludge Application Rate†† (m tons/ha)	Cumulative Total Sludge§ (m tons/ha)
Macon, GA	11	28§	308†
Las Virgenes, CA	7	50	149
Wilmington, OH	17	6.8	116
Springfield, MO	15	15.8	237
Chippewa Falls, WI	6	16§§	80§§
Hopkinsville, KY	9	22§§	66§§
Frankfort, IN	12	30§§	360§§
Kendallville, IN	13	19.7	81
Columbus, IN	5	65	326

††1975

§Through Dec. 31, 1975

§§Estimated

for agricultural use. Three other states (Georgia, California and Indiana) were in the process of adopting similar guidelines, however, Missouri and Kentucky had no proposed guidelines. Major study findings included:

- Local health officials in all seven states reported no instance of health problems attributed to sludge utilization practices.
- Sludge utilization at two sites had minimal adverse environmental impacts. Two of the nine study sites exhibited a potential for adverse environmental impacts because of, in one case, sludges having high cadmium levels (1,500 ppm) and acidic course-textured soil in close proximity to groundwater.
- Close analytical agreement was found between the levels of cadmium, copper, nickel and zinc in soil and plant composites.
- Treatment plant record keeping for sludge utilization was inadequate in terms of the quantities of sludge transported to specific farms and the locations for spreading in particular farms.
- PCBs were detected in surface soil at all but two sites. No health significance was attributable to such levels.
- Potential microbial pathogens such as Salmonella sp were not isolated in any of the stabilized sludges.
- No Salmonella or Shigella sp were detected in any of the crop-plant samples.
- No parasitic helminth ova were detected in any of the composite surface soil samples.
- In all cases, the concentrations of key metals found in subsurface soil sections and within depth increments were within the ranges typically reported for soils.

- Zinc movement to depths below 15 cm was evident in coarse-textured acid soils.
- Metal accumulation in surface soil of plots that were spread with sludge were generally higher than control plots.
- The subsurface soil data indicated that potential groundwater contamination from sludge spreading was unlikely. In one case, however, zinc had migrated to a soil depth of 122 cm under conditions in which the groundwater table was located between 120 to 150 cm.
- In general, the concentrations of cadmium, copper, nickel and zinc observed in the majority of plants and grain were within normal ranges except for the following.
    - Zinc concentrations in grass from Macon, Georgia were at potentially phytotoxic levels.
    - Cadmium concentrations in wheat grains from Frankfort, Indiana were unusually high and would have exceeded a World Health Organization recommendation for a typical daily diet.

The study of nine landspreading facilities contained the following conclusion: "the study results tend to confirm that with proper site management and crop selection, as well as careful attention to soil, crop, and sludge compatibility, little or no adverse environmental impacts will result from sludge utilization for agricultural purposes."

The economics of landspreading at nine sites was also reported, and the cost per metric ton was found to range between $7.98 and $79.08 for eight of the sites. A cost of $128.07 per metric ton was incurred at the ninth site where sludge was dewatered (EPA 1977a). The study results strongly suggest that the majority of landspreading facilities were operationally efficient and that little uncertainty in the associated technology was evident. The record keeping and monitoring systems were however found to be inadequate.

Technology - Specific Considerations

To ensure safe and environmentally sound sludge use, a number of design and operational parameters must be considered to determine allowable application rates. Of utmost concern are the sludge characteristics (nutrients, heavy metals, pathogens, salts and percent solids), application site conditions (soil type, Cation Exchange Capacity (CEC), pH, topography, surface water and hydrogeologic conditions and surrounding land use) and management procedures (controlled or monitored application site versus unrestricted operations/public give-away programs, application techniques, operations during adverse weather conditions, agricultural management programs and crop market).

Two of the most widely employed parameters for determining allowable sludge loadings to the land are the nutrient and heavy metal contents of the sludge. These critical issues, along with two others, namely, pathogens and the salt content of sludges, are discussed below.

Nutrient Loadings

For land application systems, sludge loadings are generally based on agronomic application rates. Nitrogen is generally the controlling factor in crop nutrient requirements for short-term (5 to 10 years) considerations.

The application of sludge beyond the amount calculated to supply nitrogen to crops is generally acknowledged to constitute poor management because of the high potential for pollution of groundwater by nitrates. Nitrogen availability to crops depends on three factors, (1) the ammonia nitrogen content of the sludge that is readily available, (2) the mineralization rate of organic nitrogen, which determines the amount of nitrogen, available to the crop over a number of growing seasons and (3) the application method, since substantial volatilization losses of ammonia nitrogen may occur if the sludge is applied on the surface and not readily incorporated into the soil. Because of the slow availability of organic nitrogen to the crop, allowable nitrogen loadings are generally based on initial 4- or 5-year application cycles to achieve steady-state conditions. The Draft EIS estimated an allowable sludge loading of approximately 10 dry tons per acre based on nitrogen limitations. This loading seems reasonable, especially for dispersed-site systems that may not be closely monitored.

A large fraction of the nitrogen contained in liquid digested sludge is in the form of soluble ammonia. In the dewatering process, most of this nitrogen is lost in the liquid recycle stream. Smaller amounts of soluble organic nitrogen compounds are also lost. The preliminary engineering report for Boston sludge management planning estimated that 70% of the ammonia and 20% of the organic-nitrogen in Deer and Nut Islands sludges would be lost in the dewatering process. Assuming that 10 dry tons per acre is an acceptable loading for liquid sludges, loadings as high as 20 dry-tons per acre may be required to meet agronomic quantities of nitrogen with dewatered sludge.

Heavy Metals

During the past five years, the potential impacts of heavy metals contained in sludges applied to cropland have been an issue of considerable controversy. The heavy metals of greatest concern to sludge utilization programs are cadmium, copper, nickel, zinc and lead, with the most emphasis on cadmium. Little federal guidance was available in final form until November 2, 1977 when EPA published a Technical Bulletin (Fed. Reg. Vol. 42 p. 57420). Until recently, experts in the field held divergent views on the maximum tolerable sludge metal levels. Some felt that only sludges containing cadmium levels of less than 25 ppm were suitable for growing crops (Chaney 1973). Others argued that much higher levels could be safely applied. The latter view was evident in the case of Chicago, which has applied sludges containing several hundred ppm of cadmium to its Fulton County site (EPA 1976).

The view that now appears to be emerging with somewhat broader agreement among specialists is that potential adverse impacts of metals can be controlled through proper management of three interrelated factors (EPA 1977a). These include (1) the type of crop grown, (2) the quantity of metals applied to the land (annual and cumulative loadings) and (3) the pH of the soil.

1) The type of crop is important since metals such as cadmium more readily enter the leafy portions of crops than the grain or root portions. Thus, the selection of a crop permits a degree of control over cadmium uptake.

2) The annual and cumulative loadings of metals provide a quantitative framework for assessing the soil's capacity to bind metals. The cation exchange capacity (CEC) of the soil, in particular, governs the degree to which metals are bound and thereby controls metals leaching into the soil solution and to a limited extent, the availalibility to plants. Thus, annual and cumulative loadings of metals need to be evaluated to prevent the CEC of a given soil from being exceeded. Metal loadings to soil also must be known to keep metal levels in soil below concentrations that are toxic to plants.

3) The pH of the soil also strongly governs the uptake of metals by plants. Since most of the metals of concern are present in soil as insoluble precipitates under neutral to basic conditions, their availability to plants is lessened. Alternatively, acid soils ($pH < 6.5$) facilitate metal movement into plants and groundwater.

Early Regulations Governing Metals in Study Area

An early version of EPA's Draft Technical Bulletin on sludge recommended that sludge application rates should be based on the concentration of heavy metals and nitrogen. The application rate (dry tons/acre) was to be computed by the use of a zinc equivalents equation.* This equation assumed that the toxicities of copper (Cu) and nickel (Ni) could be expressed as a zinc (Zn) equivalent and that the toxicities of these

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*Application Rate or total residuals applied as dry weight tons/acre

$$= \frac{36{,}000 \times \text{CEC}}{\text{ppm Zn} + 2(\text{ppm Cu}) + 4(\text{ppm Ni}) - 300}$$

three metals were additive to plants. The Draft EIS (EcolSciences 1976) used this method to compute sludge loadings, but modified the formula to make it even more conservative. The Draft EIS determined that, based on metal restrictions, an application rate of 10 dry tons per acre per year would be possible for only a 6-year period, resulting in a significant loss in cost effectiveness of the land option. Another early recommendation by regulatory agencies was the use of the cadmium to zinc ratio, which assumed that, with a cadmium to zinc ratio of less than 1 to 2%, zinc concentrations in the soil would be sufficient to kill crops before adverse levels of cadmium in the food chain developed. Considerable controversy developed in response to EPA's early draft document, and the numerical portions were deleted in EPA's final version of its Technical Bulletin (Fed. Reg. Vol. 42, P. 57420).

Emerging Guidelines

In addition to its recently published Technical Bulletin (Fed. Reg. Vol. 42, P. 57420), EPA plans by early 1978 to publish guidance on approaches to controlling the uptake of cadmium by food chain crops grown on sludge amended soils. These approaches will be described in EPA's "Proposed Regulations for Classification of Solid Waste Disposal Facilities" and will provide the criteria by which states will ultimately determine whether a land disposal site may remain in operation. The "Criteria Document" (Sec. 4004 of PL 94-580) would declare a landspreading facility to be environmentally acceptable with regard to cadmium uptake if "the resulting levels of cadmium in the crops or meats are analyzed and shown to be comparable to those levels present in similar crops or meats where solid waste has not been applied." A facility could also be declared environmentally acceptable if the following sludge application conditions were met. In this case, extensive testing of the crop would not be necessary.

The four conditions are:

1) The annual application of cadmium from sludge must not exceed 2.0 kg/hectare (ha) before December 31, 1981, 1.25 kg/ha between January 1, 1982 and December 31, 1985 and 0.5 kg/ha beginning January 1, 1986.

2) Maximum cumulative cadmium application to any hectare of land may not exceed 5 kg on soils with a CEC less than 5; 10 kg on soil with a CEC between 5 and 15 and 20 kg on soils with a CEC greater than 15.

3) Sludges containing cadmium concentrations in excess of 20 mg/kg dry weight may not be applied to sites where tobacco, leafy vegetables or root crops will be grown for human consumption.

4) Sludges containing cadmium must be applied so that the pH of the sludge and soil mixture is maintained at 6.5 or greater.

Based on the present cadmium content of MDC sludge, these emerging regulations will affect Boston in the following ways:

1) MDC sludge could be applied at nitrogen limiting rates until 1986. At that time cadmium would be the limiting rate and would be applied at 40% of its former application factor. (If the concentration of cadmium was reduced to 40% of its present levels, full agronomic loading rates based on nitrogen would apply.)

2) The combination of annual and cumulative cadmium loadings would limit the total sludge application period to a range of 5 to 20 years.

In conclusion, the emerging federal guidelines on metals do not indicate that a significant environmental problem would be posed by the present MDC sludge were it to be applied on a land application facility operated under standard agronomic practices. Even if cadmium levels of MDC sludge remained at their present level, agronomic loading rates (based on nitrogen) could be continued under conditions where the crop was monitored.

Such considerations would favor a large MDC-owned sludge application system over a privately-owned facility. In the latter case, proper regulatory control at the state level (in the form of a permit system with soil analyses and crop management information) would be required for sludge use on dispersed, privately farmed sites.

The heavy metals levels in most municipal sludges pose a potential public health risk when sludges are used in an uninformed fashion by home gardeners. If heavy metal contents in the Boston sludge are not significantly reduced in the future by the enactment and enforcement of industrial pretreatment ordinances, any sludge marketing or give-away programs of composted or heat-dried sludge may need to be relegated to noncrop-producing users such as golf courses, plant nurseries, park districts and flower gardens, unless adequate control techniques are used.

Salt Effects

The Draft EIS indicated that as a result of the high sodium chloride content of Deer Island sludge (approximately 2,000 mg/ℓ chloride) some problems using liquid sludge as a soil conditioner and fertilizer* may exist. The problem results from the effects of sodium on the clay fraction of the soils. Sodium causes swelling of the clay particles, thereby reducing soil water permeability, which can further result in an accumulation of excess salts in the root zone, causing plant toxicity. The potential for such problems is measured by the Sodium Absorption Ratio (SAR). Soils with low magnesium and calcium contents are particularly sensitive to sodium effects. The Draft EIS reported that in the case of dewatered Deer Island sludge, sufficient calcium would be added during lime conditioning to prevent unacceptable SAR values (EcolSciences 1976).

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*Sodium chloride presently enters the sewerage system as a result of seawater intrusion through defective stormwater overflow tide gates. The MDC is under a NPDES compliance schedule to eliminate salt water intrusion through defective tide gates. Nut Island sludges are low in salt content.

For the Nut and Deer Island liquid digested sludges, no analyses on calcium and magnesium content have been found in previous reports. However, information on the calcium and magnesium content of digested sludge was made available to ERT by Deer Island treatment plant personnel.* The SAR of Deer Island sludge is shown below:

$$\mathrm{SAR} = \frac{\mathrm{Na\ meq}/\ell}{\sqrt{\dfrac{\mathrm{Mg\ meq}/\ell + \mathrm{Ca\ meq}/\ell}{2}}} = \frac{950/23}{\sqrt{350/20 + 39/12}} = 12.6$$

While an SAR value of 12.6 in waste materials is moderately high and may cause salt toxicity problems for such salt-sensitive plants as green beans, it would not be harmful to those crops that will probably be grown on sludge amended soils, for example, corn or hay. It is generally recognized that wastewaters with SAR values greater than 15 should be avoided because of the detrimental effect on soil structure (Carlile and Philips 1976). The practice of adding lime to maintain the soil pH at 6.5 or greater would also serve to counter any sodium impacts on soil. Thus, the soil and plant problems that would be caused by the present levels of salts contained in MDC liquid sludges in the short term do not appear to be significant under conditions of normal agronomic practices. For the long-term agricultural uses of Deer Island sludges, a reduction in salt levels appears warranted.

A potential problem also exists as a result of the leaching of soluble salts into the groundwater system. The application of approximately 400 lbs of chloride-containing sludge per acre per year in conjunction with a 48-inch annual rainfall would produce a dissolved chloride concentration that would vary with the soil type.** If 50% of the rainfall percolated into the soil, then the maximum concentration of the chloride percolate would be approximately 80 mg/ℓ. If 100% percolated into a sandy soil, the resulting concentration would be 40 mg/ℓ. These concentrations of chloride are not insignificant from a public health standpoint, and further assessment would be required.

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*Data from August 1977, 31 day composite of digested sludge, calcium (Ca) 350 ppm, magnesium (Mg) 39 ppm and sodium (Na) 950 ppm.

**Assumed loading rate: 10 dry tons/acre, 5% solids.

In conclusion, the current level of salt present in Deer Island sludge presents some potential for soil and groundwater impacts. However, both types of impacts can be readily mediated or avoided. The sodium impact can be easily managed using standard agronomic liming practices. The groundwater impacts are best avoided by reducing salt water intrusion to MDC wastewater.

Public Health Considerations

In addition to the heavy metal concerns, sludge programs should be reviewed to determine the potential for transmission of bacterial or viral disease, which is related to both the number and types of disease organisms present, as well as to the nature of human contact. The types of pathogens fall into three well known categories, namely, bacteria, viruses and parasites. The major routes of human exposure include direct contact through ingestion of contaminated food and water, and contact with contaminated air, water and soil.

The majority of reports of disease transmission by sludge have been related to the use of raw or unstabilized sludges for growing human food crops (Sepp 1971; Kreuz 1955; Krogen 1954). The paucity of literature on recent accounts of U.S. disease episodes caused by landspreading of sludges may be related to two factors: (1) stabilization processes such as aerobic and anaerobic digestion significantly reduce the numbers of disease-causing organisms and (2) the great majority of U.S. sludge projects use these forms of stabilization. The reduction in the numbers of bacterial and viral disease organisms by an anaerobic digestion stabilization prorgram is particularly well documented (McKenney et al. 1959; Kabler 1959; Lund et al. 1969). However, some prominent protozoans, noteably the cysts of *E. histolytica* are unaffected by anaerobic digestion (Kabler 1959).

The absence of any clear cut evidence that links landspreading of stabilized sludge to disease episodes may also be caused by the high infective dose of a particular disease organism that is needed for disease initiation (Dupont and Hornick 1973).

While reported U.S. data on disease transmission from the agricultural uses of stabilized sludges is nearly nonexistent, the potential for sludge-transmitted disease is present, particularly in sludge giveaway programs where a degree of stabilization greater than that achieved using anaerobic digestion may be necessary. Overall, the degree of public health risk associated with landspreading of stabilized sludge is difficult to quantify, but appears to be relatively minor, especially in the case of a centralized municipal-operated facility.

Because of this uncertainty, some public health officials have adopted what can be best described as a zero risk viewpoint. This view frequently results in recommendations for costly stabilization methods, such as high temperature pasteurization or sterilization. Other public health officials have reflected a less stringent approach and view stabilization processes as adequate for the treatment of disease organisms as long as monitoring data is available to substantiate the level of exposure or if the growth of human vegatable crops is restricted.

In the Boston Case Study, the Draft EIS reported that no published Massachusetts standards that specified the type of stabilization required for sludges to be landspread existed. The Draft EIS, however, did recommend that sludge be heat pasteurized. This recommendation was made as a result of a personal communication between EcolSciences and Paul Anderson of the Massachusetts Department of Environmental Quality Engineering. The emerging federal guidelines may help to eliminate this form of arbitrary decision making as to what constitutes acceptable stabilization procedures. In its Technical Bulletin (FR Vol. 42, p. 57423) EPA provides guidance on the general requirements for stabilization and specifically uses anaerobic digestion as its standard of performance for an acceptable stabilization procedure.

Land Application - Design Criteria

ERT has developed design criteria for land application processes to evaluate (in Section 3) the cost effectiveness of several modes of land application. Certain features are common to any option and will become the basic design criteria for the land application alternative.

These features include sludge composition, sludge quantity, regional climatological characteristics and storage requirements. Since the percent solids content of the sludge is a major design consideration, two sets of design criteria are presented in Table 2.4-2. One set corresponds to liquid sludge with a 5% solids content. The other set corresponds to dewatered sludge with a 25% solids content. The major difference between the sets, in addition to volume reduction, is the reduction in the nitrogen content of the sludge.

Sludge Loadings

The amount of sludge that can be used on land will be limited by land use and sludge composition. In the case of land application for agricultural production (one type of land use), the nutrient and heavy metals composition of the sludge will be the limiting factors in determining loadings on a per-acre basis. The composition of Deer and Nut Islands sludges is described in Section 2.2.2. The design criteria (Table 2.4-2) can be used with composition data to generate annual and daily quantities.

Current practices in land application technology indicate that acceptable loading rates for municipal sludges range from 5 to 15 tons per acre per year. The sludge loading rates shown in Table 2.4-3 have been generated using nitrogen and cadmium as potential limiting factors.

Nitrogen

When the nitrogen contained in digested municipal sludge is applied to land, it enters the complex biochemical cycle shown in Figure 2.4-1. For planning purposes, this model can be simplified by identifying the most critical nitrogen forms (N) and conversion pathways (K). Based on the literature (Beauchamp and Moyer 1974) and the experiences at Chicago (Lue-Hing et al. 1975) the following nitrogen forms and transfer pathways are the most critical to the cycling of sludge applied nitrogen.

TABLE 2.4-2

LAND APPLICATION - BASIC DESIGN DATA
(Deer and Nut Islands)

Variable	Value*
A. Liquid sludge @ 5% solids	
I. Annual Quantities	
a) flow	197×10^6 gallons
b) total solids	43,600 dry tons
c) total nitrogen	2,200 dry tons
as ammonia	840 dry tons
as organic nitrogen	1,360 dry tons
d) heavy metals	
chromium	76,000 lb
copper	115,700 lb
cadmium	4,745 lb
lead	36,500 lb
nickel	25,900 lb
silver	5,100 lb
zinc	222,650 lb
II. Daily Quantities @ 60 days of application	
a) flow	3.28×10^6 gallons
b) total soilds	727 dry tons
c) total nitrogen	37 dry tons
as ammonia	14 dry tons
as organic nitrogen	23 dry tons
d) heavy metals	
chromium	1,220 lb
copper	1,930 lb
cadmium	79 lb
lead	610 lb
nickel	430 lb
silver	85 lb
zinc	3,710 lb

TABLE 2.4-2 (Continued)

Variable	Value*
III. Daily Quantities @ 120 days of application	
a) flow	1.64 x 10^6 gallons
b) total solids	363 dry tons
c) total nitrogen	18 dry tons
as ammonia	7 dry tons
as organic	11 dry tons
d) heavy metals	
chromium	610 lb
copper	365 lb
cadmium	40 lb
lead	305 lb
nickel	215 lb
silver	43 lb
zinc	1,855 lb
IV. Required Storage	
a) minimum application period	240 days
b) maximum continuous storage	120 days
c) storage volume	64.8 million gallons 198 acre-ft
B. Dewatered Sludge @ 25% solids*	
I. Annual Quantities	
a) total solids	46,540 dry tons
b) total nitrogen	1,340 dry tons
as ammonia	250 dry tons
as organic nitrogen	1,090 dry tons
II. Daily Quantities @ 60 days of application	
a) total solids	776 dry tons
b) total nitrogen	22 dry tons
as ammonia	4 dry tons
as organic nitrogen	18 dry tons

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*Dewatering will not change the metal content of the sludge.

TABLE 2.4-2 (Continued)

Variable	Value
III. Daily Quantities @ 120 days of application	
a) total solids	388 dry tons
b) total nitrogen	11 dry tons
as ammonia	2 dry tons
as organic nitrogen	9 dry tons
IV. Required Storage	
a) minimum application period	240 days
b) maximum continuous storage	120 days
c) storage quantity	15,300 dry tons 306,000 ft^3

Source: Calculated from data in Section 2.2.2.

TABLE 2.4-3

COMPARISON OF TOTAL SLUDGE LOADS TO NITROGEN AND CADMIUM LOADS

Variable	Sludge Load (ton/acre/yr) 5	10	15
Liquid Sludge			
Total Nitrogen,lb/acre/yr*	504	1,008	1,512
as ammonia, lb/acre/yr	193	386	579
as organic, lb/acre/yr	311	622	933
Cadmium, lb/acre/yr	0.54	1.08	1.62
Dewatered Sludge			
Total Nitrogen, lb/acre/yr	288	576	864
as ammonia, lb/acre/yr	54	108	162
as organic, lb/acre/yr	234	468	702
Cadmium, lb/acre/yr**	0.51	1.02	1.53

*lb/acre x 1.12 = Kg/ha

**The dry-weight concentration of cadmium in dewatered sludge is less than in liquid sludge due to the addition of conditioning chemicals.

Source: Calculated from data presented in Section 2.2.2.

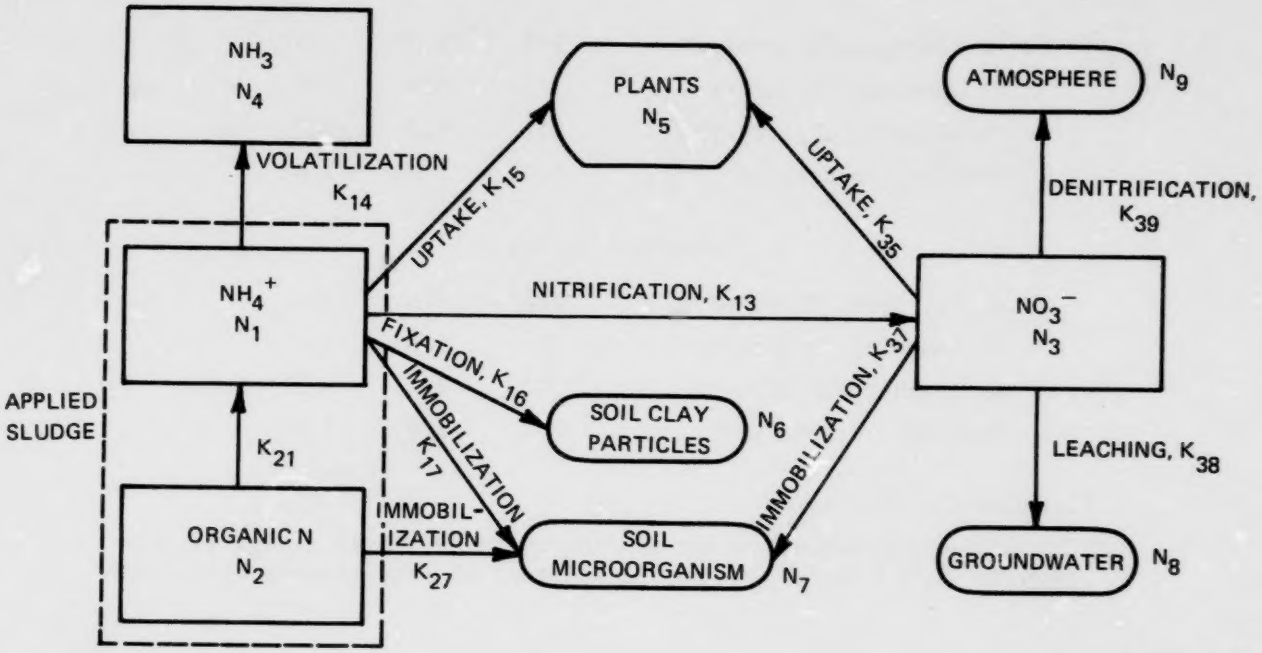
NH3
N4
VOLATILIZATION
K14
PLANTS
N5
UPTAKE, K15
UPTAKE, K35
ATMOSPHERE
N9
DENITRIFICATION,
K39
NH4+
N1
NITRIFICATION, K13
NO3−
N3
FIXATION, K16
IMMOBILIZATION
K17
SOIL CLAY
PARTICLES
N6
IMMOBILIZATION, K37
APPLIED
SLUDGE
K21
LEACHING, K38
ORGANIC N
N2
IMMOBIL-
IZATION
K27
SOIL
MICROORGANISM
N7
GROUNDWATER
N8

Figure 2.4-1 Nitrogen Biochemical Cycle

Source: Adapted from Beauchamp and Moyer 1974

Nitrogen forms:

N_1	applied ammonia
N_2	applied organic nitrogen
N_4	ammonia volatilized
N_5	total nitrogen utilized by crops
N_8	nitrate leached to groundwater

Key transfer pathways:

K_{21}	mineralization rate
K_{14}	volatilization rate
K_{15} and K_{35}	total nitrogen uptake rate
K_{39}, K_{16}	other miscellaneous losses

The amount of inorganic nitrogen in the soil at any time represents the total nitrogen available for crops. In terms of plant uptake, it is not important whether available nitrogen is in the form of nitrate (NO_3^-) or ammonium (NH_4^+). However, it is assumed that all residual inorganic nitrogen will be lost by either denitrification or leaching of NO_3^- or fixation of NH_4^+ in the soil.

The Metropolitan Sanitary District of Greater Chicago (Lue-Hing et al. 1975) has experienced first year mineralization rates equal to 35% of the total applied organic nitrogen. Also, when sludge was incorporated into the soil rather than used on the surface, only 20% of the available ammonium was lost by volatilization of NH_3. Assuming that the combination of losses caused by denitrification of NO_3, and fixation of NH_4^+ is equal to 20% of the inorganic nitrogen remaining after volatilization of NH_3, the remaining inorganic nitrogen is either available for uptake or will be leached.

The first year nitrogen budgets shown in Tables 2.4-4 and 2.4-5 are, of course, only approximations, since the critical transformations occur simultaneously rather than sequentially. However, the purpose of this analysis is only to determine the approximate minimum application rate that will ensure that agronomic quantities of nitrogen are available

TABLE 2.4-4

FIRST YEAR NITROGEN BUDGET, LIQUID SLUDGE
(incorporated into soil)

	Sludge Load (tons/acre/yr)					
	5		10		15	
Item	NH_4^+	ORG	NH_4^+	ORG	NH_4^+	ORG
Nitrogen applied, lb/acre/yr	193	311	386	622	579	933
35% ORG-N mineralized	+109	-109	+218	-218	+327	-327
	302	202	604	404	906	606
20% NH_3 volatilized	-60		-120		-181	
	242	202	484	404	725	606
20% miscellaneous losses*	-48		-97		-145	
	194	202	387	404	580	606
Uptake @ 200 lb/acre/yr	-200		-200		-200	
	-6	202	187	404	380	606
Leached Nitrogen, lb/acre/yr	0	-	187	-	380	-

*Includes immobilization of NH_4^+ in soil and denitrification of $NO_3^=$.

TABLE 2.4-5

FIRST YEAR NITROGEN BUDGET, DEWATERED SLUDGE (incorporated into soil)

	Sludge Load (tons/acre/yr)					
	5		10		15	
Item	NH_4^+	ORG	NH_4^+	ORG	NH_4^+	ORG
Ntrogen Applied, lb/acre/yr	54	234	108	468	162	702
35% ORG-N mineralized	+ 82	-82	+164	-164	+246	-246
	136	152	272	304	408	456
20% NH_3 volatilized	- 27		- 54		-82	
	109	152	218	304	326	456
20% miscellaneous losses*	- 22		- 44		- 65	
	87	152	174	304	261	456
Uptake @ 200 lb/acre/yr	-200		-200		-200	
Net Nitrogen -	-113	152	- 26	304	61	456
Leached Nitrogen lb/acre/yr	0	-	0	-	61	-

*Includes immobilization of NH_4^+ in soil and denitrification of $NO_3^=$.

for producing adequate yields of corn grain. In this respect, 10 tons per acre per year of liquid sludge and 15 tons per acre per year of dewatered sludge would be acceptable rates. At these rates, cadmium loadings (see Table 2.4-3) would still comply with acceptable EPA criteria.

Impact of Sludge Management Issues

Secondary Sludge Considerations

The planning process for 1985 primary sludge must consider the increased generation of residuals by the implementation of secondary treatment. By 1995, the quantity of sludge generated at Deer and Nut Islands treatment plants is expected to triple, thus, effectively tripling the land required for land application of 1985 primary sludge alone. Both the capital and O&M costs of the land application facility will be sensitive to the quantity of secondary sludges. Pipeline transport for 1985 sludges would have to be oversized or additional piping facilities installed to accommodate 1995 quantities. Additional trucks, barges or trains would be required for secondary sludges. Costs for storage and application will increase proportionally with land area. However, additional land will result in additional dollar returns for the product crop. If economies of scale are considered for land application facilities, then the larger 1995 facility may be more cost-effective than the 1985 facility discussed in this report.

The issue of secondary sludge quality is concerned with heavy metals and, therefore, the issue of industrial pretreatment. If the quality of secondary sludges is similar to that of primary sludges (see Section 2.2.2), cadmium loads will remain at 1.0 to 1.5 pound per acre per year (see Table 2.4-3). There are two mechanisms for reducing the per-acre cadmium load in the future. These are:

1) reducing the total sludge application rate and
2) reducing the heavy metal content of the sludge.

The first method not only increases costs by increasing land requirements, but may also result in insufficient quantities of nutrients for good crop yields. The second method requires source control of industrial contributions of heavy metals. Such a pretreatment will reduce the heavy metal content of both primary and secondary sludges.

2.4.2 Composted Sludge Utilization

A number of sludge management systems have demonstrated sludge composting to be a technically feasible and economically viable method of converting municipal sludge into a useful soil conditioner and low grade fertilizer. Sludge composting minimizes potential problems or concerns associated with landspreading of conventionally digested sludge by providing a more stabilized end product resulting in greater pathogen destruction and elimination of objectionable odors. The resulting composting sludge product is generally more acceptable to the public for reuse.

Process Description

Composting can provide additional stabilization of sludge organic matter and pathogens. The USDA has extensively investigated the composting of various types of municipal sewage sludge at their Agricultural Research Center at Beltsville, Maryland. Windrow and aerated static pile composting are the two most studied methods.

Windrow composting involves mixing dewatered sludge cake with a bulking agent, such as wood chips, and placing the mixture in windrows, typically six feet high and seven feet wide. To maintain aerobic conditions, windrow composting machines are used to turn the piles daily. Composting times depend on weather conditions, sludge characteristics and temperatures developed within the windrows. After a typical 2-week composting period, the compost is dried and further stabilized over a 1-month period in curing piles. Composted material is screened to recycle wood chips before ultimate use as a soil conditioner or low grade fertilizer. Solids contents generally range between 40 and 50%. At the Beltsville operation, compost processed from 70 dry tons of sludge per week is hauled away by bulk users at their own expense.

When raw sludge was composted using the windrow method, odor problems resulted, leading to the development of a second sludge composting method using a mechanically aerated static pile process. Unlike the windrow process, the composting material is not turned in the aerated pile process. Dewatered sludge and a bulking agent, such as wood chips, are generally mixed in a 1:2 or 1:3 volumetric ratio. A 6-inch base layer of the sludge-wood chip mixture is spread on a composting pad. A loop of perforated plastic pipe is laid on this base layer and connected to a sump for water vapor control and then to a blower, which in turn is connected by a solid plastic pipe to a scrubber pile of wood ships and screened compost. The perforated plastic pipe is then covered with an additional 6-inch layer of the sludge-wood chip mixture. Next the pile is covered with a 12-inch layer of screened compost to maintain high temperatures within the pile and to control odors. Aerobic conditions are maintained during a typical 3-week composting period either by blowing air into or suctioning it out of the pile. The stabilized material can then be dried, screened and further stabilized by storage in curing piles for one month.

Based on the Beltsville experience, one acre for a sluge processing rate of three dry tons per day is the land area requirement for sludge composting. Approximately 30% of the land is for storage; 60% for roads, mixing, composting and drying pads and the remainder for site drainage controls and leachate collection and treatment.

Review of Local Studies

The previous sludge management studies conducted for the Boston Metropolitan Area, namely, the H&E 1973 report for the MDC and the 1976 Draft EIS prepared for the EPA Region I by EcolSciences, Inc., did not formulate or analyze any sludge management alternatives that included sludge composting as an integral system component. However, it should be noted that before the 1973 H&E report, the state-of-the-art of sludge composting had not been demonstrated as a technically or economically feasible alternative for municipal sludge management. Since that time, much research and actual operating experience throughout the nation have demonstrated the feasibility of sludge composting systems. Why the EPA Draft EIS did not consider composting a potential treatment and disposal option is not clear. Composting was definitely emerging as a documented technology during the time that the Draft EIS was being prepared. Currently, the MDC is sponsoring a demonstration project related to aerated pile composting of their primary digested sludge.

Review of Other Studies

As previously mentioned, much of the sewage sludge composting research conducted during the past decade has been investigated at the USDA's Beltsville, Maryland, Agricultural Research Center. Based on the results of these research programs, plans are underway in Washington, D.C. to compost 125 dry tons per day of dewatered sludge (half raw, half digested). This capacity represents one-third of the total sludge expected to be generated at the Blue Plains treatment plant when advanced treatment facilities are installed in 1979 (Cassel 1977). Currently, member communities receive a ration of filter cake in proportion to their waste load to the treatment plant. The static pile aeration method of composting will be used on a 30-acre site adjacent to the existing treatment facilities. The capacity of this compost operation was based on the ability to use the composted sludge in the Washington, D.C. area. The remaining 250 dry tons of filter cake generated in Washington will be incinerated.

A Water Pollution Control Plant located in Carson, CA, jointly operated by the County Sanitation Districts of Los Angeles County and Orange County, has been windrow composting dewatered sludge since 1972 at a capacity of 100 dry tons per day (TPD). In 1977 this system was expanded to 300 TPD. All of the composted sludge is sold at $2.00 per dry ton to a private company that uses it as a fertilizer base for a variety of fertilizer and soil conditioner products.

The Orange County Sanitation District also has paid a private company to haul 100 TPD of dewatered filter cake sludge approximately 15 to 20 miles to a rural composting operation. This operation started in 1960 with the composted product sold for use as a fertilizer.

El Paso, Texas has composted sludge since 1938. The majority of the sludge is dewatered in drying beds and windrow composted with a 50-50 mixture of sawdust. Currently 25,000 cubic yards are produced annually and sold for $5.00 per cubic yard. Small lots are given away free for customer pick-up. Fertilizer value of the compost is 1-1-1*. Currently the demand for compost exceeds the supply. Compost purchasers include home building contractors, homeowners, schools, park districts and the highway department.

Durham, New Hampshire has conducted a static pile aeration compost demonstration program for the primary sludge generated from their 1 mgd sewage treatment plant. The composted material (15 cubic yards per week) is used as a top dressing on park projects and for landscaping along highways or is given to home gardeners. Plans for a secondary treatment plant include a 30-cubic-yard-per-week mechanized and automated aerated compost operation. It is estimated that the total cost for such a system is approximately $20.00 per cubic yard. However, 95% state and federal funding of the capital costs will reduce the net cost for Durham residents to approximately $5.00 per cubic yard.

Bangor, Maine has received an EPA grant to demonstrate the feasibility of sludge composting in a cold weather climate. To date no significant problems have surfaced with the aerated static pile compost system. Approximately 50 to 60 cubic yards are produced per week. Individuals can purchase 90 pound bags for $1.00 or make bulk purchases at $5.00 per cubic yard. Approximately half the compost is sold to city departments and the rest used by private individuals. It is estimated that Bangor's net cost for composting is approximately $6.00 per cubic yard ($32.00 per dry ton).

The MSD of Greater Chicago plans to enter the sod farming business in 1978. Four dry tons per day of sludge presently produced by the MSD's 6-mgd Hanover Sewage Treatment Plant will be used to grow sod. The sod will, in turn, be used to meet part of the demands of the Sanitary District's yearly use of sod for maintenance purposes, which currently consist of over 100 acres of sod yearly.

Air Quality Considerations

A properly managed windrow compost operation of digest sludge should not produce obnoxious odors. In the windrow compost method, heat is produced within the pile by aerobic microorganisms. Convective forces move the warm air through the windrow thereby supplying oxygen to the microorganisms. However, improper management can adversely affect air quality. For example, if there is an inadequate amount of wood chips (or other type of bulking agent) the porosity of the windrow could inhibit adequate air movement through the windrow, resulting in the development of anaerobic conditions and their attendant odor problems. On the other hand, if too much bulking agent is used, the compost pile will be too porous, thereby preventing the necessary increase in temperature required for optimum composting conditions.

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*By weight the compost is 1% nitrogen, 1% phosphoric acid and 1% potash.

Odor problems associated with windrow composting of raw sewage sludge have also been experienced. This problem led to the development of an aerated static pile process for composting raw sludge without adverse odor generation.

Water Quality Considerations

Because of the sludge/compost characteristics, which include a variety of organic and inorganic chemicals together with pathogenic organisms, water quality considerations dictate the control of water or leachate generated at the compost site, including surface runoff from precipitation and condensation that forms in aeration pipes connecting blower facilities to static compost piles.

The quantity of surface runoff depends on climatic conditions, and the size of the mixing and composting area of such areas is not housed. Neither the pollution characteristics of such leachate nor the cost of treatment have been cited in the literature. However, the location of compost facilities near the sewage treatment plant will minimize the problems and costs associated with separate leachate collection and treatment systems.

Impact of Sludge Management Issues

Secondary Sludge Considerations

Two important secondary sludge management considerations related to composting primary sludge are (1) to what extent do primary sludge composting facilities foreclose future options for secondary sludge management and (2) what is the operational flexibility of expanding primary sludge facilities to incorporate secondary sludge in the future?

Unlike incineration or agricultural utilization alternatives that require significant capital costs for incinerators or for sludge pipeline transmission systems to be amortized over the 20-year planning period, capital costs associated with composting are modest, consisting primarily of site development costs (mixing and compost pad, roadways, landscaping, surface runoff control) and equipment. The major costs associated with composting are operational in nature, namely, labor and the cost of wood chips for use as the bulking agent. Because of the relatively modest investment in facilities and equipment, sludge composting can be viewed as an interim sludge management option for sanitary districts such as the MDC. This option will in effect "buy time" so that planning for secondary sludge management can be made in the future when both the state-of-the-art and regulatory concerns related to various sludge management systems will be more clearly defined.

There are no significant technological difficulties in expanding primary sludge composting facilities to handle secondary sludges other than the increased land requirements associated with composting additional sludge quantities. Initially, composting primary sludge would require approximately a 40-acre site. Composting secondary sludge would increase total land requirements to three to four times that amount. The availability of land at the existing treatment sites may limit the expansion of composting operations to manage secondary sludges.

Note that composting does provide some inherent advantage related to secondary sludge management. Static pile aeration of raw secondary sludges would eliminate the need for costly sludge digestion facilities, also minimizing problems meeting ammonia nitrogen effluent standards caused by recycling secondary sludge digester supernatant through the treatment plant.

Heavy Metal Considerations

The major factors of concern associated with composted sludge utilization are the amount of heavy metals applied (annual and cumulative), the type of crop grown and the soil pH. The greatest concern relates to those sludge reuse programs that are not closely monitored, especially when sludge is marketed or given away free to the public for use as a soil conditioner or fertilizer in home gardens. If composted sludge contains significant heavy metal concentrations, particularly cadmium, crops such as leafy vegetables grown on acid soils (pH 6.5) may pose public health problems to the home gardener. One approach to minimize such public health concerns would be to limit the use of composted sludge to non-food chain applications such as a soil conditioner for landscaping purposes. Another approach would be to limit the heavy metal concentration in the sludge by controlling heavy metals at their source using industrial pretreatment facilities.

Public Health Considerations

The long composting and curing times, together with the high temperatures developed in the compost pile, provide a greater degree of pathogen destruction than that associated with conventional sludge digestion facilities. The increased stabilization of sludge provided by composting is an important factor related to public acceptability of composted sludge utilization programs.

Institutional Considerations

In numerous cases throughout the country, institutional problems associated with implementing municipal sludge utilization systems in rural, agricultural areas have overshadowed the technical and economic feasibility of such systems. This situation generally occurs when the sludge is traditionally viewed by the rural community as an urban waste rather than as a beneficial soil conditioner and fertilizer. An inherent institutional advantage of composted sludge utilization systems is that the demand for the stabilized product within the sewage service area in many cases exceeds the available supply.

Composting Potential for the Study Area

As mentioned previously, Region I EPA did not consider composting sludge as a treatment and disposal option in their Draft EIS.

The potential uses for compost were also not considered in the Draft EIS, although Region I EPA did perform a marketing study on the uses of dried primary sludge. The EPA study only examined the market for fertilizers. The MDC sludge would have to be fortified with nitrogen to make it competitive with miloganite, which already has an established market in the area. The EPA Study should have considered the market for a soil conditioner, for which the MDC sludge is much more suited.

The uses of compost as a soil conditioner are numerous and include home gardens, nurseries and landscape industries. A market survey of their uses conducted in Washington, D.C. concluded that the major uses of compost were for agriculture, in the production of sod for the housing market and in the maintenance and restoration of park systems (COG 1977). The latter uses were particularly important if the composted sludge contained metal levels that made the sludge unacceptable for use in vegetable gardens.

The MDC, in contrast to most other sanitary districts, includes within its functions the operation and maintenance of over 15,000 acres of park land that is increasing yearly. Approximately 1,500 acres consist of recreational fields that are intensively used. With a population in the metropolitan area of several millions, the need for resodding and maintenance of this park system could consume much of the compost or stabilized primary sludge produced at the Deer and Nut Island treatment plants.

In addition to the 15,000 acres of MDC-owned park land, the use of sod or compost by MDC highway maintenance programs would constitute another use of composted sludge. Apart from the MDC-owned and operated lands, thousands of acres of parkland exist in nearby areas of eastern Massachusetts.

An alternative use for composted sludge is the enhancement and maintenance of existing urban and suburban recreational land not necessarily owned by the MDC. Because only non-food chain land is involved, and composted sludge is highly stabilized, negligible public health hazards will be incurred. The major economic features of this option are the availability of such lands and the transport/distribution logistics.

As shown in Table 2.4-6, the Metropolitan Boston areas include considerable recreational land broken down into three categories, each of which could benefit by the use of composted sludge. Because of the location of Deer Island (where the only land for the composting facility is available) and the cost of barging material to Mystic Terminal, only available land in Middlesex and Essex counties will be considered, allowing for reduced costs for transport away from Deer Island.

The quantity of compost that can be produced at Deer Island, including both Deer and Nut Island sludges is approximately 120 dry tons/day. At a loading rate of 20 dry tons/acre, 2,190 acres of recreational land would be required, amounting to 32% of the golf course acres, or 19% of the total recreational land available in Middlesex and Essex counties.

In addition to municipal park uses of composted sludge, many private landscaping nursery and associated industries could serve as a market. In eastern Massachusetts alone, approximately 500 acres of sod are sold annually (Beesley 1977). A study quantifying such markets is currently being sponsored by the MDC.

Based on the large number of acres of MDC-owned park land and other potential markets, it appears that uses of composted sludge will exceed the supply, assuming that the necessary supply would be provided by composting all of the 1985 primary sludge.

2.4.3 Reclamation

Some land-intensive activities of man often result in severe environmental impacts to the terrestrial ecosystem. Mineral resource recovery operations such as strip mining have historically resulted in the near-complete loss of productive top soils. When located in areas where industrial, commercial or residential development is not economically feasible, these areas have been generally abandoned, as was the

TABLE 2.4-6

RECREATIONAL LAND IN EASTERN MASSACHUSETTS

(all values in acres)

County	Golf Courses	Athletic Fields	Parks and Commons
Suffolk	340	590	700
Norfolk	2,230	1,340	230
Middlesex	3,950	2,280	770
Plymouth	1,880	930	370
Worcester	3,450	1,580	350
Essex	2,870	1,570	360
Totals	14,720	8,290	2,780

Source: MacConnell 1975.

case for both the Muskegan wastewater and Chicago sludge land application facilities. These major facilities have shown that unproductive strip-mined land can be economically reclaimed using either liquid effluents or wastewater residuals. The areas involved are not only reclaimed, but also used for high-yield agricultural purposes.

The selection of this alternative requires, of course, the existence of reclaimable land. Data on such land in Massachusetts has been obtained from the University of Massachusetts aerial mapping program (MacConnell 1975). The two classifications presented in Table 2.4-7 are: SG-land used for the extraction of sand or gravel, and OM-land used for the extraction of stone and materials other than sand or gravel. With regard to this study, while these data indicate that significant acreage of such land exists, it is not known what portion of the indicated acres are abandoned and, therefore, reclaimable. Before the reclamation alternative is further considered for Boston or other Massachusetts communities, additional data is required.

2.4.4 Landfilling of Sludge

Landfilling has been widely practiced throughout the United States as the ultimate disposal method for municipal sludge. In 1976, the EPA estimated that 25% of the total municipal sludge generated in the nation was disposed by the landfill method (EPA 1976). Historically, this method of sludge disposal was often found to be cost effective when nearby sites were available, thereby minimizing transport costs; however, because of the pressures of urbanization and the large quantities of solid waste being generated in metropolitan areas, suitable landfill disposal sites are rapidly being exhausted. Furthermore, landfill operating costs have increased because of more strict environmental constraints enforced by regulatory agencies. A number of proposed landfill projects have not been implemented because of socio-political problems even though the sites were found to be environmentally suitable and within the reasonable haul distances from the service area. Thus, the landfill method of municipal sludge disposal from metropolitan areas has been decreasing.

TABLE 2.4-7

MINING LAND IN MASSACHUSETTS, BY COUNTY

	Mined Acres	
County	SG*	OM**
Plymouth	2,962	-
Bristol	3,223	-
Essex	1,971	219
Middlesex	3,923	270
Barnstable, Dukes	-	-
and Nantucket	1,268	-
Suffolk and Norfolk	-	-
Worcester	4,672	37
Franklin	829	18
Hampshire	817	-
Hampden	1,743	242
Berkshire	1,418	330
State Total	26,038	1,182

* mined for sand and gravel

**mined for stone and other materials

Source: MacConnell 1975.

Description of Process

The disposal of sludge by the landfill method depends on the appropriate local and state regulatory controls. Many landfill sites are prohibited from accepting liquid sludge or classify sewage residues as a special waste. In metropolitan areas such as Boston, transportation costs and disposal fees often dictate sludge dewatering before disposal. Often public health considerations require sludge stabilization before disposal. Combining sludge with solid waste in a landfill is a common practice. In other areas, this practice is prohibited, and the sludge is disposed in separate trenches. A number of cities have used lagoons or open landfills that are covered after many years of operation.

Many states currently require leachate controls before a site is designated suitable for sludge disposal. These controls include an impermeable membrane such as clay, bentonite or plastic liners placed at the bottom of the landfill to prevent migration of leachate from the landfill to nearby groundwater supplies. Underdrainage facilities are often placed in the landfill to collect leachate for subsequent treatment.

The landfill option is less sensitive to sludge quality than the utilization alternatives because of the level of environmental control required at any approved landfill site. Conversely, the landfill option is more sensitive to the quantity of sludge since the useful life of a given disposal site is limited by its area and fill depth. Other site-specific considerations in landfill design are liner material, cover material, equipment costs and climate. In the case of sewage, residual disposal, the means and level of stabilization must also be considered. If private landfills are used, only landfill fees must be considered. In all cases, dewatering and transport will be critical cost items.

Review of Local Studies

The recommended MDC sludge management plan by H&E (1973) included landfill disposal of an incinerator ash slurry to a man-made lagoon on the western edge of Deer Island. An 8-acre lagoon would be created by constructing a cofferdam in the harbor.

The Draft EIS recommended approval of the MDC management plan except for the ash disposal method. Because of pollution, aesthetics and the potential for other recreational uses in the harbor, the Draft EIS recommended that the incinerator ash be loaded on trailers, barged to Mystic Terminal and trucked 30 miles to the approved Plainville sanitary landfill. This alternative would dispose of 63 tons of ash per day, requiring a volume of 51.9 cubic yards assuming a 90 lb/ft^3 bulk density. Operating at a 7-foot fill depth, the annual areal requirement is 1.7 acres.

EcolSciences also considered landfilling dewatered sludge at 25% solids. Since dewatered sewage residuals are defined as a special waste according to the Commonwealth of Massachusetts landfill regulations (Division of Environmental Health 1971), special requirements must be considered. According to Plainsville's current permit, the maximum amount of material disposed daily is 750 tons (Anderson 1975). Also:

> "The Department (Department of Environmental Quality Engineering, Division of General Environmental Control) would consider the disposal of dewatered sewage residue at the site provided that the amount does not exceed 15% of the solid waste by volume." (Anderson 1975).

Deer and Nut Island primary sludge production in 1985 is 510 wet tons per day, which is equivalent to a volume of 472 cubic yards (bulk density = 80 lb/ft^3). Based on DEQE's 15% requirement, the sludge would have to be mixed with 2,675 cubic yards of waste refuse. The total quantity of fill would be 1,351 tons per day (bulk density of waste refuse = 23.3 lb/ft^3), which violates Plainville's permit. Therefore, EcolSciencies considered only landfilling half of the 1985 primary sludge (EcolSciences 1976; Alternative 6).

Review of Other Studies

The landfill option is receiving decreased emphasis on a national level, especially near the larger urban centers where available capacity is needed for municipal refuse rather than sewage residuals. Other factors include local opposition, transport requirements and advances in both high technology and other land-intensive options. The landfill alternative is being considered as an ultimate disposal mechanism for ash residue from various combustion alternatives in Boston and the New York-New Jersey metropolitan area (CDM 1976). Studies conducted nationally have indicated that for landfilling to be an acceptable practice, some form of stabilization is required (EPA 1976). Acceptable stabilization techniques are: digestion, chemical treatment, heat treatment or composting (NCWQ 1976).

Environmental Considerations

The major environmental problems associated with an operating landfill are water quality impacts to surface and groundwaters. Of these two, groundwater pollution resulting from landfill leachates is considered the most important. The quality and quantity of leachates generated at a landfill will depend on climate, type of waste, age of the landfill and soil characteristics. Most available data on the quality of leachate are related to municipal refuse, however, such data can be used to indicate the need for environmental controls.* Bruner and Keller (1972) have found that the initial leachates from a municipal refuse landfill contain high concentrations of dissolved cations, dissolved anions, nutrients and organic matter. However, over a period of time the pollutant characteristic of the leachate is substantially attenuated. These data summarized in Table 2.4-8 also show that over time the leachate becomes more acid. As shown in Table 2.4-9, Hughes et al. (1971) has documented the effect of uncontrolled leachate on unconfined groundwater wells adjacent to a solid disposal site. These data show that dissolved chloride is attentuated the least when migrating from the fill site to the monitoring well. With regard to heavy metals, Table 2.4-8 indicates that zinc and nickel derived from municipal refuse was initially soluble in percolating water. However, experimental evidence (NCWQ 1976) indicates that the heavy metals contained in sewage sludge is not soluble.

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*In Massachusetts, landfills employed for sewage residuals are required to mix sludge with municipal refuse (Anderson 1975).

TABLE 2.4-8

COMPOSITION OF INITIAL LEACHATE* FROM MUNICIPAL SOLID WASTE

Component	Study A		Study B	
	Low**	High†	Low**	High†
pH	6.0	6.5	3.7	8.5
Hardness, $CaCO_3$	890	7,600	200	550
Alkalinity, $CaCO_3$	730	9,500		
Ca	240	2,330		
Mg	64	410		
Na	85	1,700	127	3,800
K	28	1,700		
Fe (total)	6.5	220	0.12	1.640
Ferrous iron	8.7††	8.7†		
Chloride	96	2,350	47	2,340
Sulfate	84	730	20	375
Phosphate	0.3	29	2.0	130
Organic-N	2.4	465	8.0	482
NH_4-N	0.22	480	2.1	177
BOD	21,700	30,300		
COD			809	50,715
Zn			0.03	129
Ni			0.15	0.81
Suspended solids			13	26,500

*Average composition, mg/ℓ of first 1.3 liters of leachate per cubic foot of a compacted, representative municipal solid waste.

**On completion of experiment.

†At start of experiment.

††One determination.

Source: Bruner and Keller 1972.

TABLE 2.4-9

GROUNDWATER QUALITY IN THE VICINITY OF A LANDFILL*

Characteristic	Background (mg/ℓ)	Fill* (mg/ℓ)	Monitor Well* (mg/ℓ)
Total dissolved solids	636	6,712	1,506
pH	7.2	6.7	7.3
COD	20	1,863	71
Total hardness	570	4,960	820
Sodium	30	806	316
Chloride	18	1,710	248

*Groundwater quality in a saturated fill and in a monitoring well located approximately 150 ft downstream from the landfill at a depth of 11 ft in sandy, clayey silt.

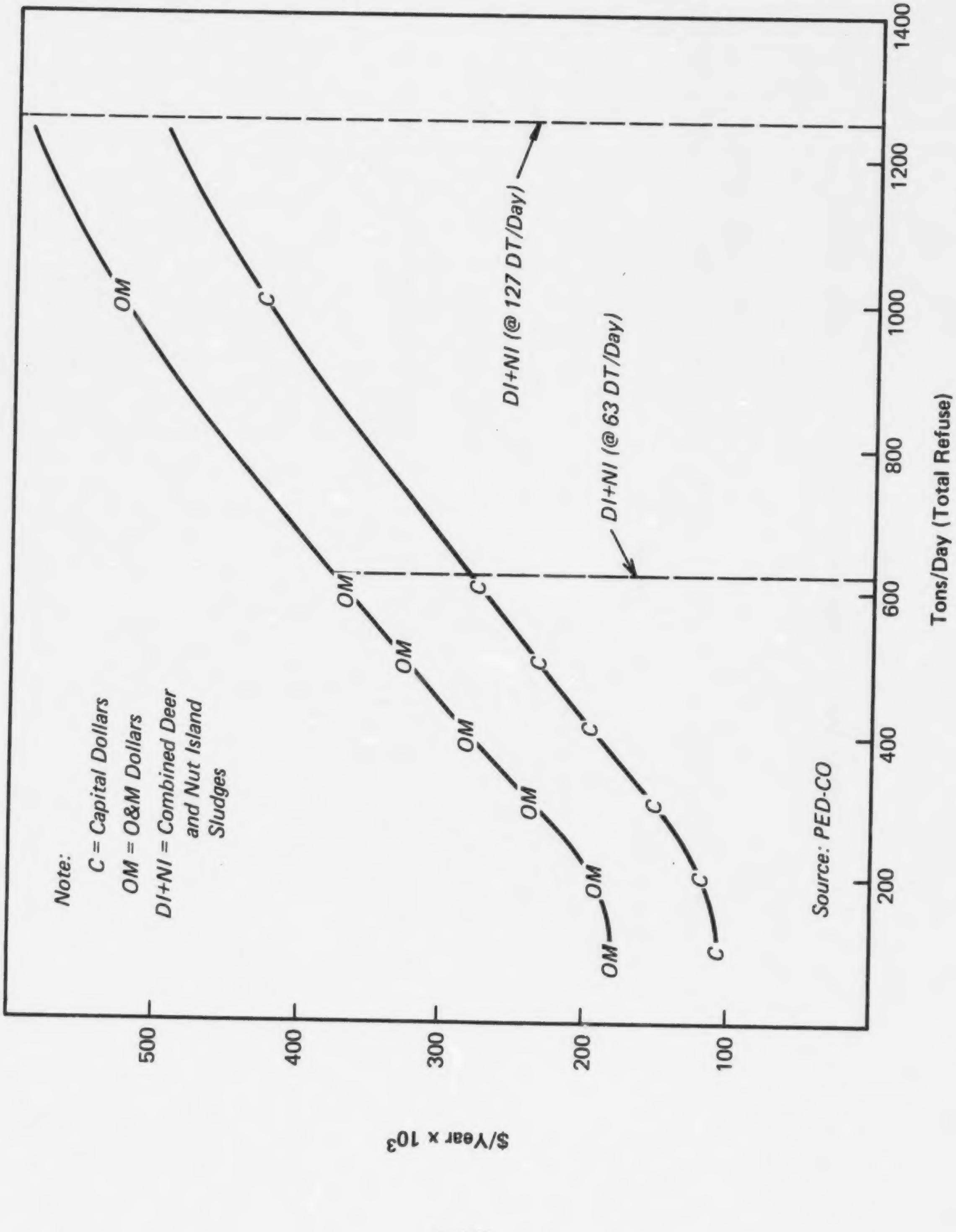
Source: Hughes et al. 1971.

Because of the lack of specific operating data on leachates from landfills, especially those used for the disposal of sewage sludge, comprehensive monitoring programs must be included in the design and cost of a landfill option. A leachate control system, such as previously described, would be employed with periodic sampling of leachate quality as well as monitoring of on-site and adjacent wells. If surface runoff is an anticipated problem, a system of collection and monitoring could be employed to prevent the discharge of polluted runoff to surface waters. Treatment of collected leachate and runoff would be provided based on need.

Economic Considerations

The major cost components of the landfill option are: dewatering (capital and O&M), transport (O&M) and landfill fees (O&M). For the privately-owned facility at Plainville, the landfill fee has been calculated at 28$/dry ton based on 25% solids sludge and a base rate of 7$/ton (Clean Communities 1977). Any proposed public landfill would be faced with severe socio-political problems, as previously stated. However, the landfill fee is costly enough to consider the public ownership option. Also, considering the quantities of sludge generated and the quantity of waste refuse required to mix with the sludge, the useful life of the Plainville facility may be severely limited.

The typical landfilling costs presented in Figure 2.4-2 are somewhat conservative in terms of fill depth and do not include land costs. These data clearly indicate some economy of scale relative to both capital and O&M cost. The Massachusetts 15% requirement indicates that for every dry ton of sewage sludge (at 25% solids) 10.5 tons of total refuse will be landfilled. Therefore, the Deer and Nut Island production of 127 dry tons/day will require a landfill capable of handling approximately 1,250 tons of fill per day. Table 2.4-10 indicates that the unit cost for a facility sized to handle all of the 1985 primary sludge would be equivalent to using the Plainville facility. However, for a smaller facility equivalent to EcolSciences' Alternative 6, the publicly-owned facility incurs a higher unit cost than the cost of using the Plainville landfill.



Source: PED-CO

Figure 2.4-2 Typical Landfill Costs

TABLE 2.4-10

COMPARISON OF LANDFILL COSTS - PUBLIC VERSUS PRIVATE (facility)

Costs ($/dry ton)	Privately-Owned	Publicly-Owned	
		127 dry tons/day	63 dry tons/day
Landfill Fee	28.00	-	-
Land Cost*		2.65	2.65
Landfill (Capital)**		11.46	12.39
Landfill (O&M)		13.54	16.52
TOTAL	28.00	27.65	31.56

*1,320 dry ton/acre = 33 acre/yr or 660 acre/20 yr, $2,500/acre; 7% for 20 yrs.

**From Figure 2.4-2, basis = 127 dry tons/day.

Impact of Sludge Management Issues

Secondary Sludge Considerations

Landfilling primary sludges at the Plainville site has already been shown to be limited by regulations established by the Commonwealth of Massachusetts. According to the Draft EIS (EcolSciences 1976), the Plainville site is capable of accepting only half of the 1985 primary production or 255 wet tons (at 25% solids). By 1995, total sludge production at Deer and Nut Island is anticipated to be 1,750 wet tons (at 25% solids). Therefore, no secondary sludge can be landfilled at Plainville, unless:

- state requirements are relaxed or
- additional capacity becomes available.

To provide a 20-year active life for the total 1985 primary sludge production, a landfill of 660 acres is required. For 1995 secondary sludge, an additional 950 acres would be required. These acreages can be reduced by using fill depths greater than 20 feet or relaxing the 15% mixing requirement for sewage residues.

2.5 Ocean Disposal

Ocean disposal of sludge by barge dumping or pipeline discharge is an important alternative for coastal cities. Low capital costs and continually available disposal sites are the main attraction of this disposal method. The choice of potential ocean sites is almost limitless compared to the problems and restrictions in locating land sites. There are no air quality impacts caused by ocean disposal; the main potential impact is on water quality and the marine biota. The type of impact will differ depending on the final disposal mode, that is, outfall or barging. In this section a distinction in definition is made between ocean dumping (barging) and the current MDC practice of ocean discharge (outfalls) to avoid confusion and clarify the broader term "disposal." A large volume of literature was reviewed, not all of which has been cited, and listed in Section 2.5.3.

2.5.1 Ocean Discharge

Description of Process

Ocean discharge is accomplished by discharging sludge into the ocean through an outfall. This is the current method of sludge disposal used by the MDC for Boston's Deer and Nut Islands treatment plants. Each primary treatment plant individually processes and mixes anaerobically treated sludge with chlorinated effluent. At Deer Island this slurry is discharged through an outfall to President Roads during the first 4 hours of ebb tide. Nut Island must pump the sludge/effluent slu[illegible] 4.2 miles across Boston Harbor to a discharge point at the tip of Long Island into President Roads.

Alternative methods of ocean discharge are possible by extending the outfalls or redirecting them so that that the discharge points are in Massachusetts Bay rather than Boston Harbor. Additional treatment steps could also be added, such as electron beam irradiation of sludge. (An MIT demonstration project employing this process is currently underway at Deer Island.)

Review of Local Studies

The search for alternative methods of sludge disposal for Boston received impetus from the Hydroscience study (1971), which reported "that the present practice of discharging sludge for the first three hours of ebbing tide results in the deposition of approximately 15 to 20% of the sewage sludge solids in the portion of the harbor west of Deer Island." Following this report, a Memorandum of Agreement was signed in October 1971 by the MDC, Division of Water Pollution Control (DWPC) and treatment plant operator. The agreement resulted in the establishment of the Boston Harbor Pollution Task Force, whose report recommended three alternatives for further study; ocean disposal was not one of the three. H&E completed their engineering report of the three recommended alternatives in August 1973. The EcolSciences Draft EIS followed, as did other studies, including this current NSF-sponsored Boston Case Study.

The Hydroscience findings that sludge back-flow into Boston Harbor is adding significantly to the pollution of the harbor appears to have been the basis and impetus for all subsequent planning studies. It is therefore important to review their findings in some detail. Hydroscience, Inc. developed a hydrographic model that predicted a back-flow of 15 to 20% of the discharged sludge. However, this was an unverified model with no actual water quality data from Boston Harbor to support the model. Drogue observations indicated that material discharged at ebb tide can (emphasis added) return on subsequent flood tides.

The New England Aquarium (1972, 1973a) undertook a study of the water quality and trace metal content of Boston Harbor water and sediments in an effort to verify the Hydroscience model. Two 24-hour tidal cycle studies were performed and the results indicated westerly fluxes in particulate phase chromium levels. The view was advanced that particulate phase chromium levels were associated with the sludge fraction of sewage, indicating that sludge from Deer Island was reaching the inner harbor. Accepting these findings as evidence for sludge impact is difficult because particulate-phase chromium could have originated from other sources. One major source would be the Deer Island sewage effluent that discharges continuously and contains particulates and chromium loads equal to or greater than that found in the sludge. Further, no definitive drogue or tracer studies that would indicate the actual dispersion pattern of sludge over tidal cycles have ever been performed.

While such studies are clearly technically feasible, there has been no interest during the last eight years on either the part of MDC, the state or EPA (Region 1 and the Narragansett Laboratory) in conducting such studies (McLeod 1977). A recent 1-year study that will address the issue of sedimentation in Boston Harbor, its origins and impacts has been initiated by marine scientists at Woods Hole Oceanographic Institute supported by Sea Grant. Although this study will directly address the issue of dispersal and fate of Deer and Nut Islands sludge, it was not initiated as part of sludge management planning in the Boston area.

Review of Other Studies

Besides Boston, the only other major coastal sludge outfalls are in California. The area is very different hydrologically and geographically from the east coast, especially because of greater depths, allowing for deeper outfalls. The California studies reveal contrasting results. The San Diego outfall was found to result in a negligible accumulation of sediment, whereas at the White's Point outfall (part of the Los Angeles system) the sludge had a definite effect on the marine biota by lowering the diversity of organisms. Alternatively, the Hyperion outfall area (main Los Angeles plant) is much deeper than White's Point, and no measurable effects on numbers of fish were observed (Reed 1975).

An extensive study was made of the marine organisms around the Hyperion outfalls using photographs to identify species (Allen 1976). Over 100 species were identified, both attached to and around the outfalls. A major unique feature of the outfall area is its hard substrate nature (versus the more common soft natural bottom). The outfall attracts rocky bottom organisms characteristic of specific depths and, therefore, although marine life is plentiful, it is not composed of the expected natural soft bottom organisms. This outfall would have to be compared with a clean rocky bottom habitat at the same depth to determine any differences in species diversity.

The Southern California Coastal Water Research Project has conducted number of studies on the effects of outfalls on the marine biota and provided valuable scientific data. The data base for Boston, in comparison, is nearly nonexistent (Barker and McLeod 1974). Other than the early work, which was sponsored by DWPC, conducted by the New England Aquarium, there have been few studies carried out on Boston Harbor directly related to the sludge pollution problem. However, it appears that this little-studied issue of sludge pollution of Boston Harbor was responsible for initiating the long and as yet incompleted sludge management planning for Boston. Another contributing factor could be the federal program for eliminating ocean discharge of sludge.

Regulatory Background

Ocean outfalls are regulated under Sections 402 and 403 of PL 92-500, Federal Water Pollution Control Act Amendments of 1972. Section 402 of the act requires a permit for ocean discharge that can be issued only if the discharge meets the criteria of Section 403. The MDC currently has a single National Pollutant Discharge Elimination System (NPDES) permit, which covers discharges from Deer Island, Nut Island and combined sewer overflows. There have been a number of violations of the permit and also of the Enforcement Compliance Schedule Letter (ECSL). The ECSL provides a schedule to bring MDC's point sources of pollution into compliance with PL 92-500. Of major interest in this discussion is the requirement of Section 301 for effluent limitations based on secondary treatment for all publicly-owned treatment works by July 1, 1977. The MDC is obviously behind in meeting this compliance schedule.

The effluent limitation requirement of Section 301 preempts the use of ocean outfalls for sludge disposal. Discharge of treated or untreated sludge separated from the main sewage stream will not meet the effluent limits based on secondary treatment. This requirement of secondary treatment appears immutable. As reported in Sludge, August 1977 (1977a), the EPA has ordered Los Angeles to install secondary treatment facilities at its Hyperion Plant and cut sludge discharge 25% by August 1978 and another 25% every six months until April 1980. On August 13, EPA filed a suit against Los Angeles "seeking injunctive relief and civil penalties for the city's failure to meet interim compliance deadlines at Hyperion with respect to both installation of secondary treatment and land disposal of sludge" (Sludge 1977a). It is obvious that the secondary treatment requirement will probably not be changed and, therefore, ocean discharge of sludge will be prohibited even though the key assumption that ocean disposal of sludge is more environmentally harmful than land alternatives has not been scientifically documented or, in the case of Boston, even addressed.

Water Quality Considerations

Should the decision be made to extend an outfall (from the present regulatory point of view this would not be possible), the laying of the pipeline would cause short-term water quality impacts. The main disturbance would be caused by an increase in turbidity, which would affect benthic organisms. However, recovery of benthic organism populations would take place. The rate of recovery would depend on a range of factors.

A fixed point discharge such as an outfall could produce long-term localized buildups of heavy metals in the sediments, changes in sediment grain size, increased sedimentation rate, anoxia and altered bottom topography. Water column quality problems would arise from increases in turbidity and dissolved metals. The impact on ambient water quality depends on the rate of discharge, pollutant loadings and plume characteristics.

The nature of the sedimentation process associated with sludge discharge through outfalls is particularly important to the long-term environment of bottom organisms. Critical issues such as the development of sludge blankets and their subsequent movement need further analysis. These issues could be significantly clarified by performing studies on the bottom areas of the existing MDC outfall.

Impact of Sludge Management Issues

Secondary Sludge Considerations

Ocean discharge of secondary sludge involves problems of environmental concern rather than space or logistics. The fixed point discharge from an outfall could be moderated to an extent with diffuser ports; the main problems would still be turbidity and heavy metals. Grain size differences could become more prominent, possibly leading to a changed habitat and establishment of new species and a different diversity. Changes in the bottom, sedimentation rate, etc., would not necessarily result in an absence of life around the outfall, but could change the types of organisms adapted to the area. The question of impact (for example, is such a change inherently undesirable) has not been addressed by the discharge criteria.

Since the outfall would have been in place for the discharge of primary sludge, there should be no additional capital cost unless a diffuser is added. The pipe should accommodate the increased quantities of sludge; the pumping rate would have to be greater, keeping the particulates stirred up longer, retarding sedimentation and creating more of a turbidity problem. The greater amounts of heavy metals might have a more immediate toxic effect on the biota. Secondary sludge should have about the same metals content as primary sludge, but the greater volume of secondary sludge discharged might cause more immediate impacts.

2.5.2 Ocean Dumping

Description of Process

Ocean dumping alternatives involve three main processes: (1) the sludge may be conditioned and dewatered, (2) disinfected or pasteurized and (3) dumped from a barge. In all the cases considered here the sludge is conditioned and dewatered by vacuum filtration to 25 to 30% solids. This process is the same as described for the incineration alternatives. Disinfection is not considered necessary for barging since the distance of the site from beaches or areas where pathogens are a particular human health problem precludes contact between the sludge and such areas. Dumping from the barge can be: (1) near the surface through a hose from a moving barge to allow for dispersal over a wide area or (2) through a bottom hopper at a single point relying on rapid settling of most of the sludge solids. This shallow-dumping-versus-deep-sites question will be discussed further elsewhere.

Review of Local Studies

Considering the lack of knowledge about marine impacts caused by ocean disposal, a general paucity of information exists in the major reports relating to Boston sludge management planning. Since Boston currently uses an outfall for sludge disposal, the pertinent literature on Boston Harbor and marine research efforts was reviewed in the Ocean Discharge Section.

After the publication of the Hydroscience study, predicting problems in Boston Harbor due to sludge back-flow, the Memorandum of Agreement led to "A Study of Alternative Methods of Sludge Disposal for the Deer Island and Nut Island Sewage Treatment Plants" by the Boston Harbor Pollution Task Force (BHPTF) in 1972. The BHPTF study reported that "the present practice of discharging digested sludge to Boston Harbor does not pose an immediate serious threat to the present uses of the water. However, this method of sludge disposal is environmentally undesirable" (BHPTF 1972).

Ocean dumping was considered a possible alternative with the following advantages and disadvantages:

Advantages

- Eliminate harbor discharge
- Low capital cost
- No air pollution
- No land needed
- Low O&M cost
- Immediate implementation
- Useful as an interim solution
- Operationally reliable
- No additional personnel needed
- Most cost effective over short term

Disadvantages

- Subject to permitting
- Does not eliminate possible ocean pollution
- No recycle or reuse value
- Possible adverse marine impacts
- Not a long-term solution
- Possible impact on water quality and sediments
- Regulation could change

Because of the unknown environmental impacts, ocean dumping was not one of the three alternatives recommended for consideration in the preliminary engineering report.

As a result of the recommendations of the BHPTF study, the H&E engineering report and environmental assessment did not address either ocean disposal alternative.

The Draft EIS (performed by EcolSciences) reviewed a broader set of alternative process trains and included ocean disposal. All trains employed dumping of sludge since outfall discharge was considered to be inflexible and would increase the chance of contact with the sludge because of the shallow, inshore sites. The choice then arose between shallow water barge spreading and deep ocean dumping. The Joint Group of Experts on the Scientific Aspects of Marine Pollution concluded, in 1974, that maximum dispersal of sludge to minimize impacts should be the chosen method, assuming the sludge meets the applicable criteria. The group also emphasized the need for recycling and reuse of wastes rather than disposal methods that transfer the material from one medium to another. EcolSciences recommended deep disposal since spreading would only disperse the high amounts of heavy metals and organics in MDC sludge over a wide area and contaminate much more of the ocean.* Another reason, based on economic considerations, was that monitoring in a deep contained site would be easier than over a wide expanse of ocean. EcolSciences recommended that, because of the unknown effects of sludge constituents on marine biota and water quality, a deep site would probably have less impact. In the Draft EIS matrix analysis and comparison of alternatives, the questionable environmental impacts of ocean disposal overrode the economic, least-cost benefit and, therefore, ocean disposal was disregarded.

Review of Other Studies

Since the local literature sources deal only briefly with ocean disposal, another key source was used extensively for information on ocean dumping experience in the New York Bight and Philadelphia dump sites. Reed's volume (1975) on ocean waste disposal practices discussed the parameters needed to study dumping effects, mechanics of monitoring programs and economic aspects and presented a number of case studies emphasizing the New York and Mid-Atlantic Bight. The discussions are based on a number of university- nad government-sponsored studies, specifically including the National Oceanic and Atmospheric Administration (NOAA) and U.S. Army Corps of Engineers Dredge Research reports. Facts and figures are presented based on baseline data, where available, and monitoring programs begun in response to the Marine Protection Research and Sanctuaries Act (MPRSA) of 1972. The volume concludes that "the technology of waste disposal has not kept pace with production...action is commencing toward a better understanding of where the major effort should be placed." The emphasis again is on the need for more knowledge before critical decisions are made.

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*The amount of dewatering will influence the settling characteristics of sludge to a great extent. EcolSciences "proposed that disposal into deep water would be attained by relying on the rapid settling characteristics of most constituents of sludge." Dewatering to about 30% solids would be necessary for barging to deep water. Reed (1975) reports that digested dewatered sludge at 10% solids has a low settling velocity and a density approximately that of sea water.

Regulatory Background

Ocean dumping has been regulated since 1972 under PL 92-532, the MPRSA. The Act resulted from the recommendations of the document, "Ocean Dumping - A National Policy" (CEQ 1970). This document allowed that some habitat changes caused by ocean dumping are not necessarily "bad" unless the result is a decrease in numbers of species and diversity. A permitting procedure, under which material could be dumped if it "will not unreasonably degrade or endanger human health, welfare or amenities or the marine environment, ecological systems or economic potentialities", was instituted. The EPA published regulations and criteria on October 15, 1973 covering ocean dumping and ocean discharge. The final revised version of the regulations and criteria published January 11, 1977 apply just to ocean dumping. Revisions of the ocean outfall criteria are expected soon.

Before the enactment of MPRSA, there was little regulation of ocean dumping. The U.S. Army Corps of Engineers had the authority to issue permits for transport of wastes, but the permits were based, not on environmental impacts, but on transportation and navigational factors. Regulations on an international scale resulted in the 1972 International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. The Convention was ratified by the Senate in 1973. MPRSA was amended in 1974 to make the Act reflect the resolutions of the convention. MPRSA then "became the enabling domestic legislation for the convention" (EPA 1977b). The original regulations and criteria of 1973 were amended in the final revision this year to incorporate the criteria of the convention.

The criteria prohibit outright the dumping of certain hazardous wastes such as biological and chemical warfare agents and high-level radioactive wastes. Other materials may be dumped under a permit if they meet criteria based on ecosystems impact determined by bioassay testing and marine water quality criteria. If these criteria are not met, as is the case with disposal of wastewater sludge, an interim permit may be issued allowing dumping until 1981 at the latest, at which time an environmentally acceptable alternative must be in operation. The EPA will issue no new permits and will only renew interim permits after April 23, 1978 if the EPA determines that the dumper is applying best efforts to comply with the requirements and has an implementation schedule for switching from ocean dumping. Interim permits have been issued to the cities of Philadelphia, New York and Camden, NJ. Camden will stop dumping by the end of this year and compost its sludge; Philadelphia is attempting to institute a land disposal alternative; and New York is looking into incineration and pyrolysis.

The EPA's 1981 end-of-ocean-dumping deadline was signed into law as an amendment to MPRSA on November 4, 1977. Known as the Hughes amendment to the MPRSA, the measure requires the EPA to "end ocean dumping of sewage sludge as soon as possible... but in no case may the administrator issue any permit or renewal thereof...which authorizes any such dumping after December 31, 1981" (Sludge 1977b). The bill, which also includes reauthorizations for MPRSA, was passed by the House Merchant Marine and Fisheries Committee on May 11, 1977. The bill and its counterpart in the Senate would allocate $4.8 million for fiscal year 1978 for the EPA's ocean dumping permit programs, $6 million for NOAA's research program and $500,000 for NOAA's Marine Sanctuaries Program. (Sludge 1977b)

The approval in committee was objected to by other committee chairmen and by both the Carter Administration and EPA Administrator, Douglas Costle. Most agree that a deadline is necessary, but argue that a legal ban would bring unnecessary pressure on those forced to comply. Because of a number of unforeseeable problems in meeting such a compliance schedule, some cities might be left with no operational sludge disposal program. Costle stated, "Placing the 1981 compliance date in the statute without provision for administrative extension for good cause would create a rigidity we believe is not necessary or advisable" (Environment Reporter 1977).

Two additional bills, H.R. 5851 in the House and S.1673 in the Senate, were introduced before their respective Merchant Marine Subcommittees in June. Both bills would mandate the 1981 ban on ocean dumping, but also would require those with interim permits to "expend adequate funds" on alternatives during the permit period. EPA would define "adequate funds," but the amount "may not be less than the money a permittee would save by continuing ocean dumping, rather than using the alternative method designated by EPA in the permit" (Sludge 1977c).

Within the permit program set up under MPRSA is a separate provision for permitting by the U.S. Army Corps of Engineers for ocean disposal of dredge materials. Dredge material is treated as a separate disposal problem mainly because it is considered a natural sedimentary material contaminated by sewage, industrial wastes or land runoff. It is not regarded as a "waste" as is sludge, but as a material regulated because of its contaminants (EPA 1977b). This distinction has been criticized by the National Wildlife Federation. In general, the criteria for dumping of sludge and dredge are very similar, but dredge consists of liquid, suspended particulate and solid phases, all of which must be tested by the bioassay procedure.

Although the U.S. Army Corps of Engineers is responsible for permitting dredge dumping, the Regional Administrator has the final say in approving a dredge permit. The dredge material must meet the same criteria as that for sludge, with a few exceptions. If the criteria are not met, and the District Engineer determines that there are no economically feasible alternatives, he may ask for a waiver. The Chief of Engineers then determines if the waiver request is reasonable and, if approved, the Secretary of the Army would request the waiver from the Administrator. There have not been any requests for a waiver since the

January 11, 1977 regulations were published (Higgins 1977). These regulations do not impose a specific phase-out date for ocean dumping of dredge material. Therefore, assuming that dredge materials meet the January criteria, dumping would be permitted beyond the 1981 end of sludge dumping date, but only in designated dump sites. Applicants for ocean dumping permits are required by the U.S. Army Corps of Engineers to discuss alternative means of disposal, but should none be feasible, a permit may be granted.

An important distinction in the U.S. Army Corps of Engineers' permit program must be made since permitting is regulated by two different laws. Ocean dumping of dredge materials is regulated under MPRSA. Dredge materials must meet the same criteria as for sludge, but if the criteria are not met, a waiver may be granted. Although the Act sets no phase-out date, it is still quite stringent, and a thorough monitoring program must accompany any ocean dumping in contrast to the permitting of dredge material disposal in inland waters, regulated under Section 404 of the Federal Water Pollution Control Act (FWPCA), PL 92-500.

No specific criteria for dumping in inland waters exist (defined as within a baseline, usually the coastline between two promontories). The majority of dredge material is dumped at these sites rather than at the much more stringent ocean sites. In Region I most of the dredging is done in Connecticut, which is conveniently located so that dredge can be disposed of in Long Island Sound. Since Long Island Sound is considered inland water, dumping regulations are much less restrictive (Higgins 1977).

Ocean dumping of sewage sludge will be ended by or around 1981. As stated in the introduction to the January 11, 1977 final regulations and criteria: "the criteria have been modified to reflect recent advances in scientific knowledge, but there is no change in EPA's intent to eliminate ocean dumping of unacceptable materials as rapidly as possible" (Federal Register 1977). Ocean dumping of dredge material will probably lessen because of the strict monitoring requirements and the availability of the inland waters sites. Should amendments to FWPCA require criteria for dumping or a phase out at these sites, then the U.S. Army Corps of Engineers will have to look at alternative disposal methods. However, since dredge constitutes 80% of the volume of the wastes disposed of in inland and ocean waters, implementation plans will have to deal with a much greater problem.

Water Quality Considerations

In general, there is a dearth of data on the impacts of ocean dumping on water quality, sediments and marine biota. In spite of this situation, many support the view that ocean dumping is a deleterious practice with little scientific data to support this view. A simple solution would be to develop substantial monitoring and research programs to supply the necessary data from which conclusions could be reached. NOAA, the federal agency that supports most ocean monitoring and research efforts, has a fiscal year 1977 budget of $5.6 million with a proposed increase (H.R. 4297) to $6 million for fiscal year 1978 (Sludge 1977b and 1976).

Since barge disposal of sludge is currently employed only by New York City and Philadelphia (both have interim permits through 1981), most of the data available is from their dumping sites off the east coast, especially from the New York Bight (NYB) area. The New York sludge dump site is about 12 miles out in 90 feet of water (72 feet according to Reed). (In contrast to EcolSciences' recommended site for Boston of 100 to 200 m.) The sludge is either treated or digested but not dewatered. Approximately 4.1 million wet tons at 5% solids are dumped annually, which constitutes about 90% of ocean-dumped sludge nationally. Therefore, the environmental effects recorded in the Bight are the main data base of knowledge to date.

The parameters of most concern include turbidity, grain size of particulates, dissolved oxygen, bacteria and pathogens, heavy metals and toxic chemicals. During the actual dumping procedure, a great deal of turbidity will exist, but the long-term turbidity will depend on the solids content and settling characteristics of the sludge. In the NYB, turbidity clouds have been observed that may disperse the particulates. "It has been stated that turbidity currents probably play an important role in the removal of waste sediment in the NY Bight, and it was suggested that the Hudson Channel may conduct such sediments to deeper water in the form of density currents" (Reed 1975). EcolSciences' review concurred with this observation in that "the apparent absence of thick coastal deposits at the NYB sludge dumpsite indicates either that the organic matter is rapidly degraded or that a transport mechanism is removing both organic and inorganic sediments" (EcolSciences 1976). Near the NYB site, crabs have been found with clogged gills, which "may have resulted from the pollution load rather than from the sediment itself" (EcolSciences 1976). Although not necessarily observed to date, possible indirect effects of turbidity and siltation include (Reed 1975):

1) reduction in light penetration and reduced photosynthesis;
2) reduction of visibility to some feeding organisms;
3) destruction of spawning areas;
4) reduction of food supplies;
5) reduction of vegetational cover;
6) trapping of organic matter, resulting in anaerobic bottom conditions;
7) flocculation of planktonic algae;
8) absorption or adsorption of organic matter or inorganic ions and
9) adsorption of oil.

Direct effects include the fouling of gills and impaired respiration of fish and invertebrates, affecting growth and survival.

Accumulation of sediments may bury benthic organisms, but they are known to be able to dig out. The long-term effect may be to wipe out the indigenous organisms that would be replaced by those more tolerant of the new sediment. Such effects must be observed on a case-by-case basis since the degree of accumulation varies with the bottom topography, currents, etc. Depending on grain size, particulates readily adsorb heavy metals, usually resulting in concentrations much higher in the sediments than in the water column. Since dissolved oxygen levels will be 2 to 3 mg/ℓ lower at a dump site than the surrounding water (Reed 1975), the heavy metals should remain in a reduced, insoluble state. But should a storm or natural mixing reaerate the sediments, the metals may become oxidized and soluble, in which state they are available for bioaccumulation.

Trace metals levels are much higher in the dump sediments than in "clean" areas, probably contributing to the reduction of species, individuals and diversity. The data shown in Table 2.5-1 (from the Draft EIS) indicate the degree of contamination in the NYB (EcolSciences 1976).

Segar and Santillo (1976) more recently concluded that:

> wastewater sludges were regarded as being minor sources of heavy metals - dredge spoil dumping and estuarine discharges were the major sources. Metals were not found to accumulate in the apex, mean residence times of heavy metals were less than six months.

The organic matter, oils and greases normally present in sludge will create an oxygen demand at the site. These organics may be rapidly degraded, but if they are persistent, such as pesticides and PCBs, they will be bioaccumulated and contaminate the marine food chain. The organic matter in sewage sludge exists in a soluble and particulate phase with an average of 23% oxidizable carbon (Reed 1975). Carbon rich sediments in the NYB were surveyed and compared to uncontaminated sediments (Reed 1975). The background sediments contained less than 0.2% total carbon. Assuming that a total carbon content of greater than 2% indicates organic matter from wastes, the NYB area covered by such wastes exceeded 50 km^2.

The greatest paucity of data to date concerns effects on the marine biota. Physical and chemical parameters are relatively easy to monitor; in contrast, accumulation studies in organisms and food chain effects are subtle and require long-term monitoring in addition to short-term acute bioassay studies. A baseline survey, or at the very least a clean area survey control study, must be conducted concurrently. The direct and indirect effect of particulates, metals, organics, anoxic conditions (oxygen levels of 2 mg/ℓ, levels too low to support a high diversity of organisms, have been found at the NYB site) (Reed 1975) and bacteria and pathogens must be monitored and indeed have been included in the monitoring data required by the permitting regulations.

Sludge may contain high levels of coliforms and pathogens that can infect fish and other organisms. Cases of fin rot, caused by environmental stress, have been observed in the NYB. Shellfish in the NYB dump

TABLE 2.5-1

TRACE METALS IN NEW YORK BIGHT SEDIMENTS

Trace Metal	Average Concentration (ppm dry sediment) Uncontaminated Sediments	Center of Sewage Sludge Dump Area
Chromium	6	105
Copper	3-5	141
Lead	12-14	170
Nickel	3-8	24
Zinc	18-20	254

site are contaminated, and the area has been closed for fishing. Bacteria are monitored by the coliform test, which only indirectly gives knowledge of pathogen contamination. Coliforms may be killed in sea water by photooxidation while other pathogens may survive. It is obvious that other bacterial testing methods are needed in addition to coliform testing.

The nutrients in sludge may be of beneficial use to algae and marine organisms as a source of enrichment. Inorganic nutrients can be considered fertilizers in this context and have been shown to increase phytoplankton, benthic populations and fish production, "but there is also evidence that efforts sometimes produce ephemeral change or unexpected new biological systems" (Reed 1975). Organic materials may also act as enrichments or growth enhancers, assuming a limiting organic is present and in available form. Similar limitations would apply for inorganic enrichments. Much more and better knowledge of the oceans, sludges and organisms is necessary before these theories can be tested (Reed 1975).

The NYB is also the site of dumping of acid, wastes, cellar dirt, radioactive wastes, chemical wastes and dredge materials. The latter is of concern because of the quantities dumped and the similarity to sludges. Depending on where the material is taken from, it may be "clean" or contaminated by heavy metals and oxygen demanding organics. It is the contaminated dredge that is of concern, mainly because of metals accumulation, oxygen demand, sedimentation and turbidity effects. The average accumulation rates for dredge and sludge from 1964 to 1968 were 32 cm per year over an 18 km^2 area and 4 mm per year over 36 km^2 area, respectively (Reed 1975). "Investigators feel that an accumulation as great as 30 cm per year may be great enough to exterminate certain benthic organisms simply by burial" (Reed 1975).

Dredge material grain densities are approximately twice as large as those of sludges (Reed 1975). Therefore, dredge material should disperse less and settle faster and possibly create less of a turbidity problem. Since monitoring is less strict for dredge disposal than sludge, environmental effects of dredge disposal have been estimated based on laboratory studies. Laboratory studies conducted by the U.S. Army Corps of Engineers have indicated that acute chemical effects on the water column above a dump site are insignificant. Metals seemed to remain insoluble in the sediments and therefore did not pose a threat to the biota. Nutrients were released in "significant quantities". Generally, the sediments adsorbed organics and metals, and the water column was relatively uncontaminated. These lab results have been followed with field studies to verify the data (EPA 1976b). Turbidity studies of clean and polluted dredge at concentrations 100 to 400 times the normal level during disposal operations indicated some mortality of benthic organisms (EPA 1976). If the dredge material is dumped in an area of similar sized sediment grains, the burying effects can be minimized.

Sludge and dredge effects in the NYB were compared in the Draft EIS on Dumping of Sewage Sludge in the NYB (Dames and Moore 1976). Total loading and mass loadings, shown in Tables 2.5-2 and 2.5-3, indicate that, for these parameters, dredge dumping should be of greatest concern. These data support the arguments of those who feel that separate and less strict regulation of dredge dumping is unjustified.

In conclusion, the data to date raised as many questions and needs for further research as they answered. A number of general statements can be made, however, as to the effects of ocean dumping from the studies completed so far.

1) Large volumes of sludge accumulated from years of dumping create a "desert" within the center of the site.

2) Sludge does disperse both within the water column and along the bottom because of currents.

3) Coliforms, pathogens and toxic chemicals can kill or contaminate marine life within 5 to 10 miles of the dump site.

4) Most of the heavy metals, persistent organics and bacteria adsorb to particulates and settle in the sediments.

5) Much more research and funding is needed to accurately predict the fate of sludge in the ocean and its impact on the water column sediments and marine biota.

TABLE 2.5-2

LOADINGS OF HEAVY METALS IN BIGHT APEX

Metal	Wastewater Sludge Loadings (metric tons/day*)	Total Bight Loadings (metric tons/day*)	Percentage from Wastewater Sludge
Cadmium	0.044	2.4	1.8
Chromium	0.073	5.0	1.5
Copper	0.7	13.8	5.1
Lead	0.72	12.7	5.7
Mercury	0.013	0.3	4.3
Zinc	1.8	33.0	5.5

*1 metric ton = 1.10 tons

Source: Mueller and Jeris, unpublished data (Dames and Moore 1976).

TABLE 2.5-3

COMPARISON OF DREDGED MATERIAL AND WASTEWATER SLUDGE MASS LOADS

Variable	Dredged Material*	Wastewater Sludge*	Dredged Material to Wastewater Sludge Loading Ratio
Total solids	13,000	530	25.28
Biochemical oxygen demand (BOD_5)	200	210	0.95
Chemical oxygen demand	1,100	2,100	0.52
Total organic carbon	110	540	0.20
Oil and grease	22	300	0.07
Total Kjeldahl nitrogen	63	17	3.70
Total phosphorous	63	17	3.70
Cadmium	2.0	0.04	50.00
Chromium	2.3	0.073	31.50
Copper	6.3	0.70	9.00
Mercury	0.013	0.013	1.00
Lead	4.7	0.72	6.53
Zinc	7.3	1.8	4.06

*in metric tons/day (1 metric ton = 1.10 tons)

Source: Mueller and Jeris, unpublished report (Dames and Moore 1976).

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APPENDIX 2A

SLUDGE METAL CONCENTRATION DATA
FISCAL 1974-1977 TABLES

TABLE 1

DEER ISLAND - FISCAL 1974 - 1977

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	40	40	40	40	40	40	40	40	40
ΣX_i	49,373	71,176	2,787	17,453	12,270	2,579	132,656	239.4	253
$\overline{X}$	1,234	1,779	70	436	307	64	3,316	6.0	6.3
X_{max}	5,352	5,774	146	1,007	657	275	9,108	12.2	14.3
X_{min}	167	147	10	55	88	14	833	1.6	2.5
$\Sigma(X_i - \overline{X})^2$	31,533,787	64,084,980	41,739	2,354,027	686,050	102,833	139,620,400	-	-
σ	888	1,266	32	243	131	51	1,868	-	-
$\sigma/\overline{X}$	0.72	0.71	0.46	0.56	0.43	0.80	0.56	-	-

TABLE 2

DEER ISLAND - FISCAL 1974

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	9	9	9	9	9	9	9	9	9
ΣX_i	8,255	11,002	651	4,166	2,600	455	25,615	51.3	58.7
$\overline{X}$	917	1,222	72	463	289	51	2,846	5.7	6.5
X_{max}	1,470	2,580	134	843	530	96	6,352	11.4	13.3
X_{min}	278	277	10	222	88	14	944	2.5	2.5
$\Sigma(X_i - \overline{X})^2$	4,475,312	3,584,604	11,167	277,907	200,427	6,746	18,988,459	-	-
σ	705	631	35	176	129	27	1,453	-	-
$\sigma/\overline{X}$	0.77	0.52	0.49	0.38	0.45	0.53	0.51	-	-

Source: MDC

N = number of samples

ΣX_i = sum of sample values X_i over $i = 1,N$

$\overline{X}$ = mean value of N samples

$\Sigma(X_i - \overline{X})^2$ =

σ = standard deviation

$\sigma/\overline{X}$ = standard error of the mean

TABLE 3

DEER ISLAND - FISCAL 1975

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	9	9	9	9	9	9	9	9	9
ΣX_i	9,072	20,504	700	2,568	2,793	437	29,486	60.2	52.8
$\overline{X}$	1,008	2,278	78	285	310	49	3,276	6.7	5.9
X_{max}	2,237	5,000	123	521	474	108	6,346	9.2	9.4
X_{min}	167	446	13	84	126	21	833	3.4	2.5
$\Sigma(X_i - \overline{X})^2$	2,997,750	18,216,968	10,235	233,007	69,845	5,684	42,536,872	-	-
σ	577	1,422	34	161	88	25	2,174	-	-
$\sigma/\overline{X}$	0.57	0.62	0.44	0.56	0.28	0.51	0.66	-	-

TABLE 4•

DEER ISLAND - FISCAL 1976

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	12	12	12	12	12	12	12	12	12
ΣX_i	23,491	30,145	904	5,321	4,177	1,170	51,802	82.9	96.6
$\overline{X}$	1,957	2,512	75	443	348	98	4,317	6.9	8.1
X_{max}	5,352	5,774	146	789	657	275	9,108	12.2	33
X_{min}	688	974	25	55	127	18	1,695	1.6	2.7
$\Sigma(X_i - \overline{X})^2$	17,750,423	22,705,645	12,610	718,088	286,703	68,330	55,562,276	-	-
σ	1,216	1,376	32	245	155	75	2,152	-	-
$\sigma/\overline{X}$	0.62	0.55	0.43	0.55	0.45	0.77	0.50	-	-

Source: MDC

N = number of samples

ΣX_i = sum of sample values X_i over $i = 1,N$

$\overline{X}$ = mean value of N samples

$\Sigma(X_i - \overline{X})^2$ =

σ = standard deviation

$\sigma/\overline{X}$ = standard error of the mean

TABLE 5

DEER ISLAND - FISCAL 1977

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	10	10	10	10	10	10	10	10	10
ΣX_i	8,555	9,525	532	5,398	2,700	517	25,753	45	44.9
$\overline{X}$	856	953	53	540	270	52	2,575	4.5	4.5
X_{max}	1,103	1,618	79	1,007	426	80	3,725	6.3	6.1
X_{min}	595	147	11	184	132	21	1,762	3.6	2.6
$\Sigma(X_i - \overline{X})^2$	227,969	1,267,079	4,022	794,740	92,080	3,903	3,025,033	-	-
σ	151	356	20	282	96	20	550	-	-
$\sigma/\overline{X}$	0.18	0.37	0.38	0.54	0.36	0.38	0.21	-	-

TABLE 6

NUT ISLAND - FISCAL 1974-1977

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	40	41	41	41	41	41	41	41	22
ΣX_i	8,332	25,739	1,464	15,672	11,551	1,911	52,124	260	191
$\overline{X}$	208	628	36	382	282	47	1,271	6.3	8.7
X_{max}	727	1,936	180	1,136	1,558	145	2,436	50	42
X_{min}	18	136	2	58	35	5	172	0.2	2
$\Sigma(X_i - \overline{X})^2$	827,644	5,623,797	46,372	2,128,188	3,010,971	39,670	9,563,683	2,888	1,775
σ	145	370	34	288	271	31	483	8.4	9.0
$\sigma/\overline{X}$	0.70	0.59	0.94	0.60	0.96	0.66	0.38	1.30	1.30

Source: MDC

N = number of samples

ΣX_i = sum of sample values X_i over $i = 1,N$

$\overline{X}$ = mean value of N samples

$\Sigma(X_i - \overline{X})^2$ =

σ = standard deviation

$\sigma/\overline{X}$ = standard error of the mean

TABLE 7

NUT ISLAND - FISCAL 1974

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	7	7	7	7	7	7	7	7	7
ΣX_i	1,712	3,369	533	3,152	2,470	323	7,416	43.1	85.6
$\bar{X}$	245	481	76	450	353	46	1,059	6.2	12.2
X_{max}	419	736	180	714	769	90	1,515	9.0	19
X_{min}	55	323	23	139	81	23	769	4.2	5
$\Sigma(X_i - \bar{X})^2$	82,789	115,908	17,159	282,784	318,831	3,201	515,199	40.8	186.9
σ	109	129	50	201	213	21	271	2.4	5.2
$\sigma/\bar{X}$	0.44	0.27	0.66	0.45	0.60	0.46	0.25	0.39	0.43

TABLE 8

NUT ISLAND - FISCAL 1975

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	11	11	11	11	11	11	11	11	10
ΣX_i	2,603	7,459	310	3,615	4,004	332	13,096	79.5	84.5
$\bar{X}$	237	678	28	329	364	30	1,191	7.2	8.5
X_{max}	727	1,306	68	688	1,558	65	1,774	24	42
X_{min}	29	218	15	88	118	10	570	1	2
$\Sigma(X_i - \bar{X})^2$	366,012	1,082,248	3,114	366,292	1,778,754	4,184	1,336,581	354.7	1426.3
σ	182	314	17	182	402	20	349	5.7	11.9
$\sigma/\bar{X}$	0.77	0.46	0.61	0.55	1.10	0.67	0.29	0.79	1.40

Source: MDC

N = number of samples
ΣX_i = sum of sample values X_i over $i = 1,N$
$\bar{X}$ = mean value of N samples
$\Sigma(X_i - \bar{X})^2$ =
σ = standard deviation
$\sigma/\bar{X}$ = standard error of the mean

TABLE 9

NUT ISLAND - FISCAL 1976

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	11	12	12	12	12	12	12	12	5
ΣX_i	2,007	7,015	345	4,432	2,654	677	16,971	52.2	21
$\overline{X}$	182	585	29	369	221	56	1,414	4	4
X_{max}	386	1,032	45	805	782	145	2,436	13	3
X_{min}	45	149	6	58	35	14	172	0.2	3
$\Sigma(X_i - \overline{X})^2$	128,543	1,047,085	3,119	525,212	418,656	16,763	5,126,767	175	5
σ	108	295	16	209	187	37	654	4	1
$\sigma/\overline{X}$	0.59	0.50	0.55	0.57	0.85	0.66	0.46	1.00	0.25

TABLE 10

NUT ISLAND - FISCAL 1977

(all values: ppm dry weight)

Variable	Cromium	Copper	Cadmium	Lead	Nickel	Silver	Zinc	Mercury	Arsenic
N	11	11	11	11	11	11	11	11	0
ΣX_i	2,010	7,896	276	4,473	2,423	579	14,641	84.7	-
$\overline{X}$	183	718	25	407	220	53	1,331	8	-
X_{max}	564	1,936	108	1,136	613	118	2,157	50	-
X_{min}	18	136	2	114	57	5	614	0.2	-
$\Sigma(X_i - \overline{X})^2$	243,359	3,153,228	9,059	881,338	299,301	10,996	1,914,754	2,237	-
σ	149	335	29	283	165	32	417	14	-
$\sigma/\overline{X}$	0.81	0.75	1.16	0.70	0.75	0.60	0.31	1.75	-

Source: MDC

N = number of samples
ΣX_i = sum of sample values X_i over i = 1,N
$\overline{X}$ = mean value of N samples
$\Sigma(X_i - \overline{X})^2$ =
σ = standard deviation
$\sigma/\overline{X}$ = standard error of the mean

APPENDIX 2B

SLUDGE TRANSPORTATION ECONOMICS

APPENDIX 2B

1. Sludge Characteristics

The basic ingredients of municipal sludges are water and solid residual of wastewater renovation processes. These basic ingredients heavily effect transportation costs of a sludge disposal system that has to use any or all of the transportation modes previously described. Sludge volume, consistency and percent solids vary, depending on the method of sludge production. The volume of sludge can be reduced by introducing dewatering facilities into the sludge production train. Sludge volume reduction will generally lower the costs of the truck, rail and barge modes of transportation. Pipelines are sensitive to sludge consistency, and the overall cost may become prohibitive with increase of the percent solids. However, in selecting the design sludge consistency, the selected method of ultimate disposal and the accompanying mechanics of materials handling must be considered. For example, it is not possible to dewater the sludge to 25% consistency for transportation economics and then expect to dispose of the material by soil incorporation via injection. It is therefore imperative that the most economical mode of transportation be consistent with the most economical mode of disposal.

2. Distance

Any method of transportation selected for a site-specific sludge disposal system represents a commitment of capital. This commitment may be in the form of purchase of means of transportation, such as trucks and trailers, railroad rolling stock, barges or pumping stations and pipelines. It may also be in the form of annual expenditure for labor required to operate the transportation system; the costs of maintenance of the transportation facilities; fees payable for use of roads, rail lines, rights-of-way, land and rental fees for locomotives or barge tow boats and other costs. Many of the costs mentioned are directly attributable to distance that has to be traveled between the point of sludge production and disposal. Some costs per ton per mile diminish as the mileage increases; however, the overall costs may increase with the total distance. It is important to arrive at the breakeven point beyond which the particular mode of transportation may become uneconomical. Therefore selection of the mode of sludge disposal may depend on the distance between the points of sludge production and disposal.

3. Contractual Aspects

In providing the most economical combination of transportation for sludge disposal, the basic issue of ownership of the means of transportation versus contracting with private enterprises to provide the service must be considered. To best illustrate the issues involved, a discussion of the inherent possibilities of each mode of transportation follows.

3.1 Truck Transportation

The truck mode is probably equally adaptable to outright ownership by the sludge producer or a contractual agreement with hauling contractor. Since roads are publicly owned, there are no special problems peculiar to this mode of transportation, except the issue of ownership of equipment. It may be cheaper for the sludge producer to purchase the truck and trailer fleet and to hire the necessary personnel to operate the equipment. However, issues such as equipment amortization, fuel costs and labor and union problems versus the lump sum fee charged by the hauling contractor motivated by profitability of the entire operation must also be considered.

3.2 Barge Transportation

Three basic factors affect consideration of barge transportation for sludge disposal: mooring fees, barge ownership and tow-boat ownership. Mooring fees are assessed for berthing and the use of facilities at the loading and unloading points. If the sludge loading is done at the sludge producer's mooring, considerable savings may be realized. Nevertheless, the mooring fee will have to be paid for the port facilities owned by anyone other than the sludge producer. Such fees will be payable by the producer regardless of contractual arrangements for the barge transportation.

The second factor to be considered is the ownership of the barge or barges. The sludge producer should consider such advantages or barge ownership as lack of profit mark-up on the amortization cost of the equipment and the equipment availability at all times. The need for maintenance and the lack of barge maintenance shops and therefore a possible transfer cost to others for this work must be considered. All of the above must be pitted against a contractual arrangement with a contractor who, due to a large volume of operation, may obtain a more favorable pricing for crews and can therefore arrive at a lower barging cost even though the profit factor has entered his overall pricing considerations.

The third factor to enter the overall pricing considerations is tow-boat operation. Operation of tow-boats on inland waterways and intercoastal or seaways is a highly complicated and regulated system and it is doubtful whether any sludge producer would want to surmount all the difficulties connected with tow-boat ownership and operation. It is therefore suggested that the sludge producer enter into contractual agreement with a tow-boat operator to provide towing services for barging. A long-term contract can be economic, and an opportunity exists for competitive bidding among various operators within any area that can be serviced by barge transport.

3.3 Rail Transportation

The rail transport mode presents difficulties similar to those encountered in barge transport. One difficulty is the obvious impossibility of developing a self-contained and independent rail haul system designed specifically and solely for the purpose of transporting sludge from a specific point of production to a point of disposal. It is necessary to use existing rail lines and construct the necessary track to provide unloading facilities next to the mainline routes. The cost of using the present rail lines and switching facilities have to be borne by the sludge producer who will pay fees to the railroad companies involved.

The only flexibility open to the sludge producer is the method of obtaining the necessary rolling stock, be it railroad cars or locomotives. When choosing to purchase both the cars and the locomotives, advantages such as lower amortization cost because of lack of mark-ups and the possible longer life of the equipment if maintained properly should be considered. The disadvantage of rolling stock ownership lies again in the fact that the sludge producer basically has no expertise in rail transportation and no necessary skills to operate and maintain such a system. On the other hand, complete reliance on a railway hauling contractor may result in noncompetitive pricing for the required services. Then the possibility of owning a fleet of railway cars built specifically for the service of sludge transportation and of contracting for locomotive services from the railroad companies located within the general service area should be considered. The advantage of operating a dedicated unit train on a year-round basis with known volume and sequence of operation can be readily appreciated by the railroad companies and translated into lower fees for the use of rail lines, switching yards, locomotives and personnel.

Rail transportation can therefore be considered as one of more inflexible modes. Main advantages would be the trains ability to transport large quantities of sludge over long land routes and the possible economic advantages of a unit train concept.

3.4 Pipeline Transportation

Pipeline transport for liquid sludge placed the most rigid requirements for commitment of sludge producer to a method of ultimate disposal and life of the disposal system. Generally, there are no private industries that would contract for construction and operation of a pipeline transportation system with a fee being received for all services rendered to the sludge producer. Therefore, there are no economies to be derived from various ways of providing a pipeline transport system. The economies may lie in providing the most economical design of a pipeline and the necessary pumping stations or booster stations. Also, the advantages of purchasing all the required rights-of-way and constructing the pipeline is such a manner as to minimize the required length and elevation changes should be considered. Therefore the sludge producer has to be prepared to bear all the burdens of constructing and operating the pipeline system, which may provide an advantage of lower unit prices for sludge transport as compared with other, more flexible modes.

APPENDIX 2C

SUMMARY OF KENNEDY ENGINEERS WASTEWATER TREATMENT ALTERNATIVES FOR THE EMMA STUDY AREA

APPENDIX 2C

SUMMARY OF KENNEDY ENGINEERS WASTEWATER TREATMENT ALTERNATIVES FOR THE EMMA STUDY AREA

Alternative I Baseline

Baseline criteria will limit the sewer service area, per capita wastewater flows, infiltration and industrial allowances and assume rehabilitation of sewers to reduce inflows in accordance with assumed EPA criteria. All treatment will be primary at Deer Island and Nut Island with effluents discharged at present locations.

A) Upgrade and rehabilitate the existing MSD facilities; serve existing sewered areas only.

B) Expand existing MSD facilities to provide adequate primary treatment to serve same flows as in IA above.

C) Expand existing MSD facilities and expanded service area to serve Year 2000 population as projected by EMMA in the existing member communities, but with limited flow allowances as in IA above.

D) Provide add-on alternatives to provide five ways of handling intermittent wet weather flows from combined sewer areas tributary to Deer Island. Kennedy Engineers will include the extra facilities needed at Deer Island:

1) retention of combined sewer overflows; extra primary treatment capacity at Deer Island;

2) automatic dry weather flushing of combined sewer deposits; extra primary treatment at Deer Island;

3) separate storage and treatment of urban stormwater;

4) street cleaning for urban runoff source control and

5) EMMA-recommended approach to combined sewer overflow problem with facilities at $270 million cost.

Alternative II EMMA-Recommended Plan

Upgrading and expanding Metropolitan Sewerage District Facilities based on criteria in EMMA Report are recommended. This report proposes two satellite AWT Plants discharging to rivers; secondary treatment at Deer Island and Nut Island with effluents discharging to Boston Harbor; and $270 million screening and detention station approach for combined sewer overflows discharging to inland rivers and estuaries.

APPENDIX 2C (Continued)

Alternative III Alternate to EMMA

(All EMMA Alternatives have $270 million combined sewer overflow projects with no modifications to provide effective treatment):

A) EMMA, without satellite plants, consolidated treatment at Nut Island; Deer Island and Nut Island secondary effluents discharged to Boston Harbor;

B) EMMA with two satellite secondary plants, effluents conveyed to Boston Harbor;

C) EMMA with two satellite secondary plants, effluents discharged to rivers adjacent to plants;

D) EMMA with two satellite lagoon treatment plants with land disposal;

E) EMMA with one satellite secondary plant, effluent conveyed to Boston Harbor;

F) EMMA with one satellite secondary plant, discharge to Neponset River;

G) EMMA with one satellite lagoon treatment plant with land disposal;

H) EMMA with one satellite AWT plant discharging to Neponset River;

I) EMMA (as in Alternative IIIA) without satellite plants, also without secondary treatment; Deer and Nut Islands, discharging primary effluent to deep ocean water and

J) EMMA, without satellite plants, without secondary treatment, discharging primary effluent to Boston Harbor.

3. IMPLICATIONS OF SLUDGE ALTERNATIVES

This section is directed at defining and evaluating a set of alternative primary sludge management options for the Boston Metropolitan Area reflecting uncertainties currently facing local planners. Some of these alternatives have been considered in detail by existing planning studies, while others are significant departures or, in fact, currently unavailable because of restrictions imposed by federal policies. The nine basic alternatives are:

- incineration
- pyrolysis
- co-combustion (with solid waste)
- ocean dumping
- ocean discharge
- composting and distribution of compost
- landfill
- land application at public sites
- land application at private sites

Detailed cost and environmental analyses of the various unit processes and other factors affecting these general sludge management alternatives were covered in Section 2. This section puts those processes together into complete sludge management alternatives, and then evaluates them for their costs, benefits, and feasibility under current planning constraints. It serves as a base for Section 4, which looks at changes in those conditions and their effect on the feasible set of alternatives.

The evaluation method used in this section varies somewhat from the common facilities planning practice, since it attempts to explicitly consider the risks of making various types of decisions. Sludge management is a field where both the technologies and the policies --

the "rules to the game" -- are changing rapidly, and there are several types of risk inherent in any decision that gets made on the local level. For example, some of the risks that the MDC would take if they chose to build a sludge incinerator might include:

- changing costs, particularly for energy, which might make the system uneconomical
- changing federal standards, which might require additional air pollution control equipment (or even make it impossible to build the incinerator once designed)
- changing technologies, and the choice of an option which has not been demonstrated in full-scale application
- potential inability to operate the system to design performance (costs change with inferior operation)
- improved availability of other cheaper or more environmentallly-sound options which would leave the MDC with a "white elephant" system

and so forth. There are three categories of uncertainty, which will be considered in various sections of Sections 3 and 4:

- planning uncertainty, which affects the ability of the agency to implement and effectively operate a facility if the decision is made under current constraints
- policy uncertainty, which includes all changes in federal regulations which may occur in the future and affect one or more alternatives
- technology uncertainty (including relative cost shifts) which may involve innovations, improvements, or failures of sludge management options.

Section 3 considers only the first category, and assumes that (lacking an accurate oracle) the decision rule used by local officials is to work within current constraints, rather than trying to outguess the vagaries of federal policy and scientific advancement. In Section 4, this base is used to analyze various policy and technology changes which could affect sludge management, and to estimate the magnitude of their impact. Policy conclusions in Section 5 are then related to the impacts of federal policy options on Boston and other areas, as demonstrated in Section 4.

This section is divided into five sections: first, Section 3.1 presents our review of the theories underlying the decision process, and the methods in use for assessing technology choices under uncertainty. These lead to a description of our own methodology, and the reasons we chose it. Then, alternative sludge management process trains are described in Section 3.2; in Section 3.3, economic impacts of the various alternatives are identified; Section 3.4 analyzes the major pollutant emissions for the alternatives; and Section 3.5 then considers institutional constraints and opportunities; and Section 3.6 develops our evaluation across sludge management alternatives, including the local trade-offs among cost, environmental impact, and political feasibility which affect choice.

3.1 Methodology for Comparing Alternatives

Three general categories of sludge management technology were described in Section 2 -- combustion options, ocean disposal options, and land application options. Each of these technologies, however, is subject to uncertainty about its cost, performance, environmental emissions, resulting environmental impacts, and feasibility of implementation. These uncertainties are large -- no incinerator of the type planned seems to be operating correctly in the United States, partly because only a few have been built. They are significant -- land application may be eliminated because there is no local understanding of how it would be implemented, or faith that it is even possible. It appears that better decisions could be made through explicit consideration of these uncertainties and risks, and this has been the basis for our approach.

The approaches shown in the past by EcolSciences and Havens & Emerson have been typical of current practice, but do not allow any explicit consideration of risk. For example, the Havens & Emerson evaluation is a pure engineering costs analysis, assuming that each alternative will perform as designed, and that the costs are certain. Evaluation is simply a matter of choosing the one with the lowest net cost, with no sensitivity analysis to identify the critical parameters and determine which costs are the most likely to be achieved in actual construction and operation. While analysis of this type is straightforward and may offer some useful insights, its neglect of any form of uncertainty makes it of limited value as the sole basis for planning.

The EcolSciences analysis in the Draft EIS is equally limited, but claims to do more. The evaluation process involves considering not only cost, but also a wide range of environmental attributes, all of which are reduced to comparable measures and linearly combined into a total score for each option. This is a simple example of a linear scoring procedure, and has uncertainty not only in the emissions, but also in their impacts, the severity with which those impacts affect society, and the interactions among the various impacts. The approach attempts to provide a rule for deciding among the options, but our evaluation and the comments prepared by others* suggest that this particular application, at least, has been a failure. A simple statement of the most significant impacts for each alternative, giving the magnitude of the emissions and expected impacts over a number of dimensions, would be preferable than the attempt in the EIS.

Since the past work provided only the weakest methodology for trading off among environmental risks and no procedure for analyzing the uncertainties present in all the alternatives for sludge management, it was necessary to develop a method for the analysis performed in this project. Before describing it, it is worthwhile to look at the goals for such a methodology, and some of the attempts which have been made to achieve these goals, and this is done in Section 3.1.1 below. Section 3.1.2 then describes our approach, including its major assumptions and limitations. The approach is implemented in the remainder of Section 3, and in Section 4.

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*See, for example, the comments prepared by the New England Consortium on Environmental Protection for the Massachusetts Executive Office of Environmental Affairs in April, 1976.

3.1.1 Analysis Goals and the State-of-the-Art

If the perfect evaluation methodology could be designed, it would have some of the following attributes: it would be deterministic, because it would perfectly analyze all impacts, and predict their result; it would, therefore, also be perfectly accurate in assessing them; it would be multi-objective, assessing all significant impacts separately; it would be able to determine the ranking of alternatives for each interested group according to their own goals; and, it would be able to perform the political trade-off among the interest groups to determine which alternative would be the most advantageous overall.

Not surprisingly, the state-of-the-art has not progressed so far. Each of the steps -- analysis, prediction, utility assessment, ranking, and the final trade-off -- is subject to limitations in methodology, data, and resource requirements (primarily cost). Uncertainty is extremely significant, particularly for sludge management, and adds an extra dimension onto all steps in the analysis. Constraints arise from the requirements of federal programs and these affect the available options and the timing of decisions. All in all, the problems are more complex than the available tools can address, and this implies that various assumptions have to be made about how things work.

Decisions Under Risk and Uncertainty

The first concern is risk and uncertainty in the technical options being evaluated. For example, costs may change over time, so that an incinerator costs more(or less) in real dollars when built than it does when designed. This might also result from changes between planning and design, since the planning step is only preliminary. When new technologies are under consideration, as is the case for most of the proposed options, these uncertainties are likely to be large, and committment to one specific alternative increases the risk of failure significantly. However, there may also be some side benefits: implementation of a new incinerator technology in Boston, for example, might aid incinerator evaluation in New York or Omaha. Congress has recently shown an intent to compensate communities who are risk-takers, by providing extra grant funding for alternatives which are innovative. The nation recognizes risks, and recognizes that advances in technology only occur when areas attempt to implement the risky options, so the extra grants are simply a way of distributing the benefits from the risky investment.* EPA may also support areas which are left with innovative options which do not work, by paying the marginal costs attributable to the failure. If this is the case, there is no incentive to avoid a risky option, and every incentive to commit to one: the costs can not go up, and may go down significantly.

Various strategies can be adopted to reduce local risks, but, in general, they involve some method for keeping the options open: either an attempt is made to delay committment to a long-term solution, or parallel options are chosen** so that, if one fails, the other(s) can make up the difference. Investment in technologies which are insensitive to inputs may also be useful: for example, ocean discharge of sludge is possible up to the capacity of the discharge pipe, and increased or reduced flows or changes in composition will not affect cost significantly. Composting, on the other hand, might be sensitive both to the composition of the sludge (e.g.,salt content) and the quantity, since it is proposed for an area on Deer Island, where land is at a premium.

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*The literature on learning processes and strategies for analyzing decisions which involve both implementation and R&D is large. See, for example, Rausser and Dean (1971).

**This involves increased security, but loss of economies of scale: the trade-off is accept increased costs, but obtain a certain solution.

In the Boston context, technological risk is likely to be extremely important. Whether an option will work or not should affect both the decision to invest in it, and an explicit analysis of the probabilities that each item can be implemented and will work appeared desirable. This also involved the economic risk, or how much the alternative would cost once implemented.

There is another form of economic risk, however, which would affect the evaluation: cost shifts due to the prediction problem in planning, design, and construction. A facilities plan includes an estimate for the cost of building and operating the plant, based on a particular design time. However, this is only an estimate, and the actual costs (for that particular time) would be drawn from a distribution around the estimate. It might be, for example, that incinerator costs would be normally distributed with a variance of 20% about the expected cost. If the distributions are normal, and the coefficient of variation is identical for each alternative, this form of uncertainty has no impact on the analysis: that assumption was made in both the Havens & Emerson and the EcolSciences analyses. However, if the distributions or the coefficients of variation change between alternatives, this form of prediction uncertainty should be considered explicitly. Given estimates of the cost distributions, this could be analyzed easily.

The economic risks, therefore, arise from two sources: first, whether the alternative as designed could be implemented and would perform as planned; and, second, whether the cost of the design would be as estimated. The environmental risks for the various alternatives arise in similar ways, analogous to the two sources of economic uncertainty. Planning is not a perfect predictor of design, nor is design a good predictor of operation, so emissions are at least as uncertain as costs in the early stages. If the equipment does not operate correctly, this will affect both costs and emissions.

Environmental impacts, however, are the major concern: emissions are only an intermediate factor. The transfer functions between emissions and impacts are unknown and lead to another type of uncertainty, simply because there is not enough knowledge of the natural processes involved.

The literature abounds with methodologies for the estimation of emissions, and of their resultant environmental impacts. These range from simple dissolved oxygen sag models for stream flows to procedures for evaluating the ecosystem effects of changes in the population of individual species. The best ones admit to uncertainty and consider it either directly or indirectly (e.g. by stochastically choosing input conditions and simulating).

The uncertainties of interest, then, arise from the inability of the analyst to perfectly understand the natural system or the technologies of interest, and from a corresponding inability to predict the future. Methods are available for explicitly considering these uncertainties in some situations, and these methods from the state-of-the-art in analysis techniques. For example, it would be possible to estimate the probability distribution of outcomes for incineration on both cost and environmental grounds, leading to joint and marginal distributions for the cost/ton and the emissions of the most critical pollutants. It would then be possible to estimate the differences between, say, incineration and pyrolysis and to determine whether any of the differences was significant. At the end of this process, the analyst would have a number of alternatives, and would know where there were significant differences in costs and environmental emissions (and perhaps environmental impacts, by adding another stage). Dominated alternatives would then be eliminated, and the remaining options would be passed on to the decision-making stage.

This process is easy to describe, but would be almost impossible to implement, without major simplifying assumptions. For example, take the first stage: this requires assessing the distribution of performance and cost for an incinerator which is currently planned with a set of design specifications. It requires knowing all the sources of uncertainty which affect incinerator cost and performance, knowing how these sources of uncertainty interact with each other, and building the performance space of incinerators through some sort of modeling. It requires thinking about the technology in an uncommon manner, and gathering immense amounts of data and expertise. Multiply this by perhaps a dozen candidate technologies, and it becomes clear that some sort of simplification is required. When it becomes apparent that the environmental impact models are expensive to run, and that explicit consideration of uncertainty means that, instead of one cost estimate, there may be a continuous distribution of projected costs which must be numerically modeled, the resource requirements for the proposed analysis appear extreme. More importantly, much of the data are unavailable for assessing such distributions. Assumptions and simplifications are made in every study because of factors such as these, and the explicit consideration of uncertainty , while desirable, can not always be done completely in every stage of an analysis. Given the characteristics of sludge management and the current technology, some consideration of uncertainty, however, should be done.

The Decision-Making Process

The uncertainties underlying actual decision-making are also large, and much less subject to analysis. The EcolSciences evaluation matrix attempted to trade-off environmental impacts to determine which alternative would be most desirable, but it did this by making assumptions about how the decision process would evaluate the various impacts, and (even more important) how it would combine them to assess each alternative. There are two ways to improve upon this. At one extreme, the analysis could have left a long list of costs and other impacts, and allowed each reader to determine which action appeared most appropriate. On the other, the analysis could have attempted to explicitly assess utility functions for the decision maker (or the various interest groups) and use the impact predictions to determine the ranking for each group. These techniques have been established and work reasonably well, given assumptions of consistency and performance of preferences, and assuming that individuals can be identified and/or groups give their preferences accurately. These assumptions, though, are often false, so that the utility assessment methods, while helpful, may not be a total answer. Use of these methods also requires significant amounts of time from all interested parties, and this is expensive.

Still, provision of a list of several hundred impacts and their relations to a dozen alternatives does not necessarily help the decision process: the decision makers are likely to be overloaded with the analysis. Such a list would be valuable as background material, but a straightforward analysis would choose out the most significant impacts and present them. The presentation of multi-objective information has been the subject of a large number of studies, with resulting methods that are helpful but probably not sufficient. There are limits at both ends: the process is limited by what it can absorb, yet the methods for analyzing and simulating the political decision-making are not effective enough to be useful as an alternative.

3.1.2 The Approach Used in This Study

It is apparent from the above discussion that uncertainty can be included in the analysis at a cost; it is also apparent that the goal should be to present results to the decision-making process effectively, but not to make the decision for that process. The major factors influencing the actual choice of method were cost and data quality, and the method was chosen in an attempt to reach the project goals within those constraints. We feel that it may also be appropriate in other situations, but this is, as with any change in technology, open to question.

In brief, the proposed approach explicitly considers the uncertainty involved in choosing a new technology by first determining the major dimensions of uncertainty for each technology. A range of cases are then chosen, with performance varying along those dimensions, and these are evaluated by conventional engineering cost analysis and emissions prediction. The goal is to get a picture of the response surface for each technology, without having to explicitly assess the probabilities of a wide range of options.

For example, consider incineration. The major dimension of uncertainty in sludge incineration for the Boston area is performance, and specifically the performance expected from sludge dewatering. A secondary dimension is the heat value of the sludge solids. Therefore, four cases were chosen for incineration, with varying levels of sludge dewatering and heating value, to represent the range of incineration performance which might be expected. These were evaluated conventionally, leading to cost variations depending on the auxiliary fuel required in each case and on other factors. In this case, the design program constrained emissions to meet standards for new sources, so the necessary pollution control practices and equipment were included in the costs for each option.

This level of analysis was performed for each of the nine alternatives described above, leading to a range of performances and costs in each case. In general, the costs were more sensitive to performance than the environmental emissions, though there was some variation on the emissions axis as well.

Environmental impacts were not considered in great detail, because of the goals of the study. The concern was to evaluate federal policies, and federal policies are demonstrated more by the setting of standards than by a concern with real local environmental impacts. It was assumed that any emission which was less than the appropriate federal standard was acceptable from the federal perspective, so that the major issues on emissions came in evaluating whether a particular technology was acceptable under standards or unacceptable, and whether the standards appeared reasonable. In a local application of the methodology, it would be necessary to analyze the environmental impacts explicitly for each level of emission, and probably to include various scenarios of impact for the significant pollutants, similar to the scenarios for technology performance. Once the standards are met, impacts are a local issue, but this does not make them any less important in the evaluation.

With respect to presentation, both costs and the most significant emissions are presented for each alternative in this section, with expected ranges where appropriate. In addition, variances (which represent the level of uncertainty for particular technologies) are presented. These may be useful in evaluating which technologies are most certain, and in trading off between risk adverseness, cost, and impacts.

The final stage in any evaluation under uncertainty should be a sensitivity analysis, and this is contained in Section 4. Specific factors -- energy costs, federal standards, new data on performance, and the like -- may greatly affect the costs and emissions of particular technologies, or the likelihood of achieving certain levels of performance. In making a decision, it is useful to have information about how these factors would affect performance, so that alternatives can be chosen which are relatively insensitive to the major exogenous forces (if any such alternatives exist).

In essence, we assume that there are five factors which can be evaluated in the analysis, and which are significant in the decision-making process. They are

- cost, where uncertainty is included through ranges in performance
- emissions, treated similarly to cost
- environmental impacts, not considered here, but subject to a scenario treatment of the transformation from emissions
- technological risk, shown by the range of cost and impact scenarios
- exogenous factors, evaluated in the sensitivity analysis of scenarios

The first three of these are considered in conventional planning studies. Given the data presented in Section 2, however, the two latter factors are likely to be of extreme importance in an area like sludge management, where technology and practices are changing rapidly, and where there is a wide range of options. While the proposed approach requires some strong assumptions about the ability of analysts to choose a set of "representative" cases, it seems to be a reasonable attempt to include these added factors while still keeping the resource requirements within reason. The remainder of Section 3, and Section 4, provide an example of its application.

3.2 Description of Sludge Management Plans

3.2.1 Combustion Alternatives

The major design uncertainties for the incineration alternative are the degree of dewatering, the heat value of the sludge and the excess air input value. Variation in these parameters results in varying fuel requirements and thus affects costs. Similar variables create cost variance for the pyrolysis alternatives. Costs for the co-incineration alternatives also vary with the type of combustion mechanism employed (incineration vs. pyrolysis) and the resulting system design. Table 3.2-1 summarizes the design factors for the combustion cases.

Alternative 1 -- Incineration

This alternative includes pumping Nut Island's digested primary sludge to Deer Island for dewatering and incineration along with digested primary sludge from Deer Island. Ash is barged 6.3 miles to Mystic terminal and trucked 30 miles to landfill in Plainville. Steam is produced to drive an on-site turbine generator to produce electricity. Cases 1A to 1D use incineration unit process data from I_1, I_2, I_3, and I_6 in Chapter 2, respectively.

Case IA -- filter presses producing a 40% solids sludge cake with 50.5% volatile solids at 11,080 btu/lb volatile solids; furnace exhaust temperature is maintained at 930°F for excess air rate at 151%.

TABLE 3.2-1

CHARACTERISTICS OF COMBUSTION CASES

Alternative	Case	% Solids in Sludge Burned	BTU/lb of Combustible Portion of Sludge	Excess Air	Fuel Use/Dry Ton of Sludge
Incineration	1A	40[1]	11,080	151%	.5[5]
	1B	30[2]	11,080	50%	3.1[5]
	1C	26[2]	11,080	52%	19.6[5]
	1D	26[2]	9,900	79%	35.4[5]
Pyrolysis	2A	40[1]	11,080	50%[4]	7.1[5]
	2B	30[1]	11,080	50%[4]	45.0[5]
	2C	26[2]	9,900	50%[4]	85.5[5]
Co-Incineration	3A	70[3]	11,080	NA	12.6[6]
Co-Pyrolysis	3B	30[2]	11,080	50%[4]	12.6[6]

[1] Filter Press

[2] Vacuum Filter

[3] Rotary Sludge Dryer

[4] In Afterburner

[5] Gallons of Fuel Oil

[6] Wet Tons of Solid Waste

Case IB -- same as Case IA, except vacuum filters used to produce a 30% solids sludge cake and furnace operated at about 50% excess air (EPA recommended plan).

Case IC -- same as Case IB except vacuum fulters producing a 26% solids sludge cake.

Case ID -- same as Case IC except low heat value sludge solids (9900 btu/lb volatile solids) and higher excess air at 79%.

Alternative 2 -- Pyrolysis

This alternative includes pumping Nut Island's digested primary sludge to Deer Island for dewatering and pyrolysis along with digested primary sludge from Deer Island. Ash is barged to Mystic terminal and trucked to landfill in Plainville. Steam is produced to drive an onsite turbine generator. Pyrolysis unit processes for cases P_1, P_2, and P_3 are incorporated into cases 2A to 2C, respectively.

Case 2A -- filter presses producing a 40% solids sludge cake with 50.5% volatile solids at 11,080 btu/lb volatile solids, excess air at 50% in afterburner.

Case 2B -- same as Case 2A except vacuum filters used to produce a 30% solids sludge cake

Case 2C -- vacuum filters producing a 26% solids sludge cake with low heat value sludge solids (9900 btu/lb volatile solids). Otherwise similar to case 2A.

Alternative 3 -- Co-Incineration

This alternative involves separate dewatering of digested primary sludge at Deer Island and Nut Island, then barging the 30% solids filter cake to Wiggins terminal, followed by trucking to a new City of Boston solid waste incinerator at South Bay. Solid waste and sludge filter cake would be burned together, and ash trucked to landfill in Plainville. Steam is produced and sold to Boston Edison.

Case 3A -- co-incineration in two water wall boilers using a rotary sludge drier to predry sludge cake to 70% solids. Incineration capacity for 1500 tpd mixed municipal refuse (MMR) and 427 wet tpd of 30% solids sludge cake. Ferrous metal recovery from ash (Stone and Webster recommended co-incineration plan).

Case 3B -- co-pyrolysis in three multiple hearth furnaces, including a front end solid waste classification plant for production of refuse derived fuel (RDF) and recovery of ferrous metal and aluminum. Furnace capacity for 900 tpd of RDF and 427 tpd of sludge cake at 30% solids.

A third case of a solid waste only system was developed to allow us to estimate the marginal cost of adding sludges. Case 3A is taken from the 1976 Stone and Webster report. See Table 2.3-5 for specific input to the heat balance program.

3.2.2 Ocean Alternative

Transport mode is the important economic factor for the ocean alternatives. Costs for ocean discharge by pipeline (Alternative 4) vary depending on the length of the outfall and the degree and type of disinfection process employed. Costs for barge dumping of dewatered sludge (Alternative 5) vary depending on the haul distance and the location of dewatering facilities. Table 3.2-2 summarizes the main parameters of interest.

Alternative 4 -- Ocean Discharge

This alternative involves discharge of digested primary sludge via submerged outfall (See figure 3.2-1).

Case 4A -- continued use of existing sludge discharge outfalls, but with addition of electron beam irradiation for pathogen destruction.

Case 4B -- anaerobically digested sludge from Nut Island is pumped to Deer Island, and the combined sludges are discharged via a 36,000' ocean outfall to a point beyond the Graves.

Alternative 5 -- Ocean Dumping

This alternative involves the barging of dewatered, digested primary sludge to ocean dump sites.

Case 5A -- digested primary sludges from Deer Island and Nut Island are separately dewatered and barged 30 miles to sea for disposal.

Case 5B -- same as Case 5A except barge distance is 70 miles.

Case 5C -- digested primary sludge from Nut Island is pumped to Deer Island for dewatering along with digested primary sludge from Deer Island. The combined dewatered sludge cake at approximately 25% solids is barged 30 miles for disposal.

Case 5D -- same as Case 5C except barge distance is 70 miles.

TABLE 3.2-2

CHARACTERISTICS OF OCEAN-RELATED CASES

Alternative	Case	Percent Solids in Transported Sludge	Distance to Site (miles)	Transport Mode	Dewatering Facilities
Ocean Discharge	4A*	5	.19 to 3.8**	pipe	NA
	4B	5	6.8	pipe	NA
Ocean Dumping	5A	25	30	barge	Separate
	5B	25	70	barge	Separate
	5C	25	30	barge	Combined at Deer Island
	5D	25	70	barge	Combined at Deer Island

*Includes electron beam disinfection

**100' from Deer Island, 20,000' from Nut Island to President Roads

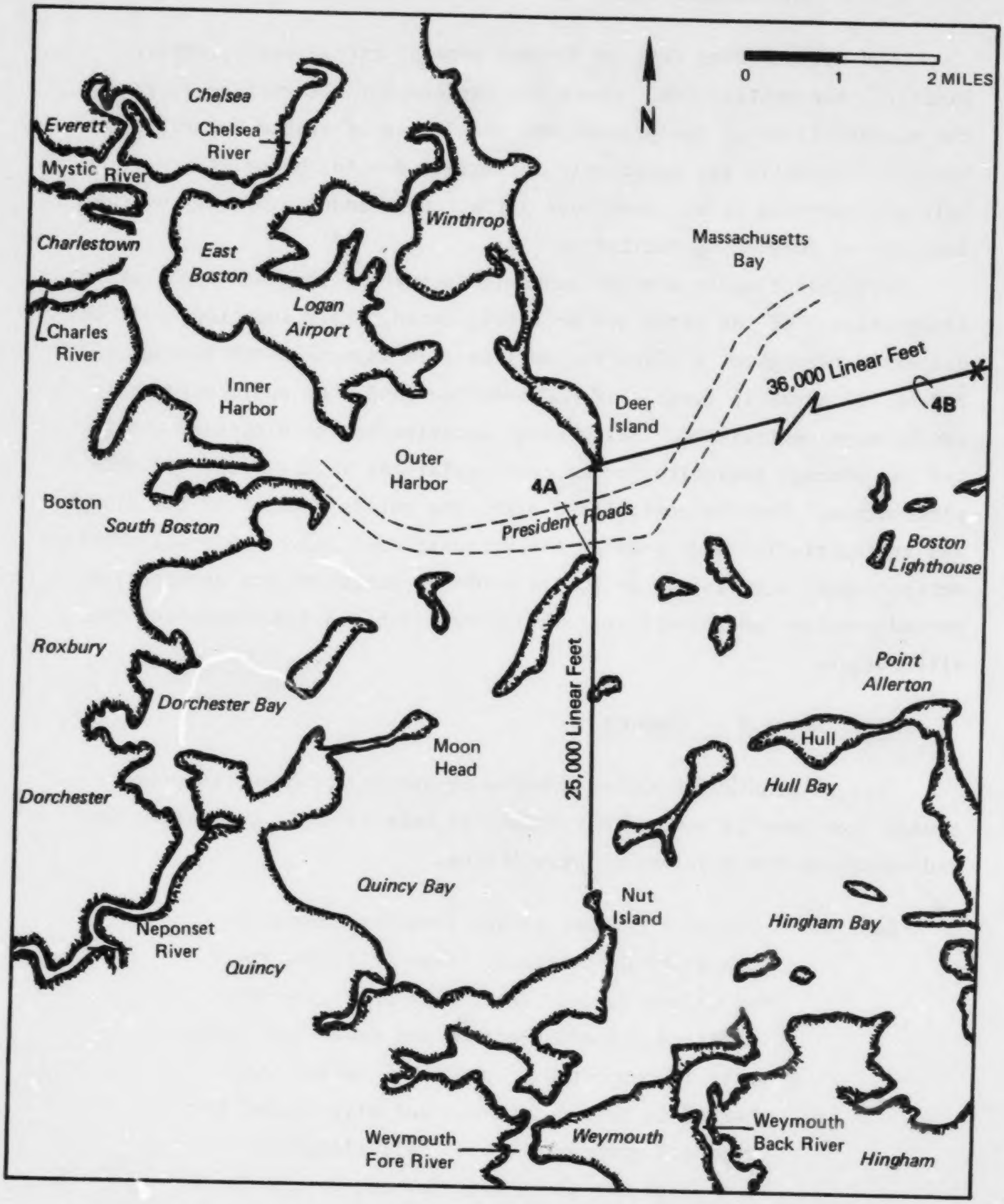

0
1
2 MILES
N
Chelsea
Everett
Chelsea River
Mystic River
Charlestown
East Boston
Winthrop
Massachusetts Bay
Logan Airport
Charles River
Inner Harbor
36,000 Linear Feet
4B
Deer Island
Outer Harbor
4A
Boston
South Boston
President Roads
Boston Lighthouse
Roxbury
25,000 Linear Feet
Point Allerton
Dorchester Bay
Hull
Moon Head
Hull Bay
Dorchester
Quincy Bay
Nut Island
Hingham Bay
Neponset River
Quincy
Weymouth Fore River
Weymouth
Weymouth Back River
Hingham

Figure 3.2-1   Alternative 4--Ocean Discharge

3.2.3 Land Alternatives

Land alternatives fall into three general categories: compost, landfill, and utilization. Costs for the compost alternative vary with the marketability of the product and the degree of system control. Costs for landfill are relatively inflexible due to the existence of only one approved site. Some cost variation is induced by varying the location of dewatering facilities.

Site selection is a major economic factor for the land application alternative. If the sites are privately owned, their locations will be dispersed throughout a given region (farms in Massachusetts average only 100 to 150 acres in size). If MDC owns the land, the application site can be more centralized. The general location of the dispersed sites and the storage logistics induce cost variations in the dispersed site alternative. For the centralized site, the solids content of the sludge and transportation mode provide the broadest cost range. For all utilization cases, uncertainty as to the probable length of the application period provides additional cost variation. Table 3.2-3 summarizes the alternatives.

Alternative 6 -- Compost

This alternative involves windrow composting of digested primary sludge from Deer Island and Nut Island at Deer Island. Composting pad and equipment are provided at Deer Island.

Case 6A -- digested primary sludge from Nut Island is pumped to Deer Island. Then it is dewatered on vacuum filters along with Deer Island's digested primary sludge. The dewatered sludge cake is composted to about 50% solids and barged to Mystic terminal and distributed to regional give-away sites. All sludge is composted and given away for use on non-food-chain crops and parkland.

Table 3.2-3

CHARACTERISTICS OF LAND RELATED CASES

Alternative	Case	Percent Solids in Applied or Transported Sludge	Distance to Site (Miles)	Land Requirement (Acres)	Loading Rate (Ton/Acre/Year)	Transport Mode	Application Period (Days/yr)	Percent of Potential Users Accepting Sludge
Composting	6A	25[1]	NA	40	NA	barge/truck	NA	NA
Composting/Landfill	6B	25[1]	NA	330[2]	1320	barge/truck	NA	NA
Landfill	7A	25	41	660[2]	1320	barge/truck[3]	365	NA
	7B	25	36	660[2]	1320	barge/truck	365	NA
Land Application (Dispersed, privately owned sites)	8A	5	53	4380	10	pipe	120	68%
	8B	5	53	4380	10	pipe	60	68%
	8C	5	76	4380	10	pipe	120	23%
	8D	5	76	4380	10	pipe	60	23%
	8E	5	129	4380	10	pipe	60	17%
Land Application (Centralized, MDC owned site)	9A	5	53	5040	10	pipe	120	NA
	9B	5	53	5040	10	pipe	60	NA
	9C	25	53	3600	15	barge/truck	120	NA
	9D	25	53	3600	15	barge/truck	60	NA

[1] Solids content of sludge before composting.

[2] Dedicated landfill, 20 year active life, acres/year.

[3] DI and NI sludge dewatered separately and transported by barge making a loop including VI, NI, and the Mystic Terminal.

NA = Not Applicable.

Case 6B -- same as Case 6A except capital cost is increased to provide weather protection for compost area and operating cost is increased for doubling the cost of wood chips. One half of the sludge cannot be disposed by compost give-away and must be barged and trucked to landfill instead of composting.

Alternative 7 -- Landfill

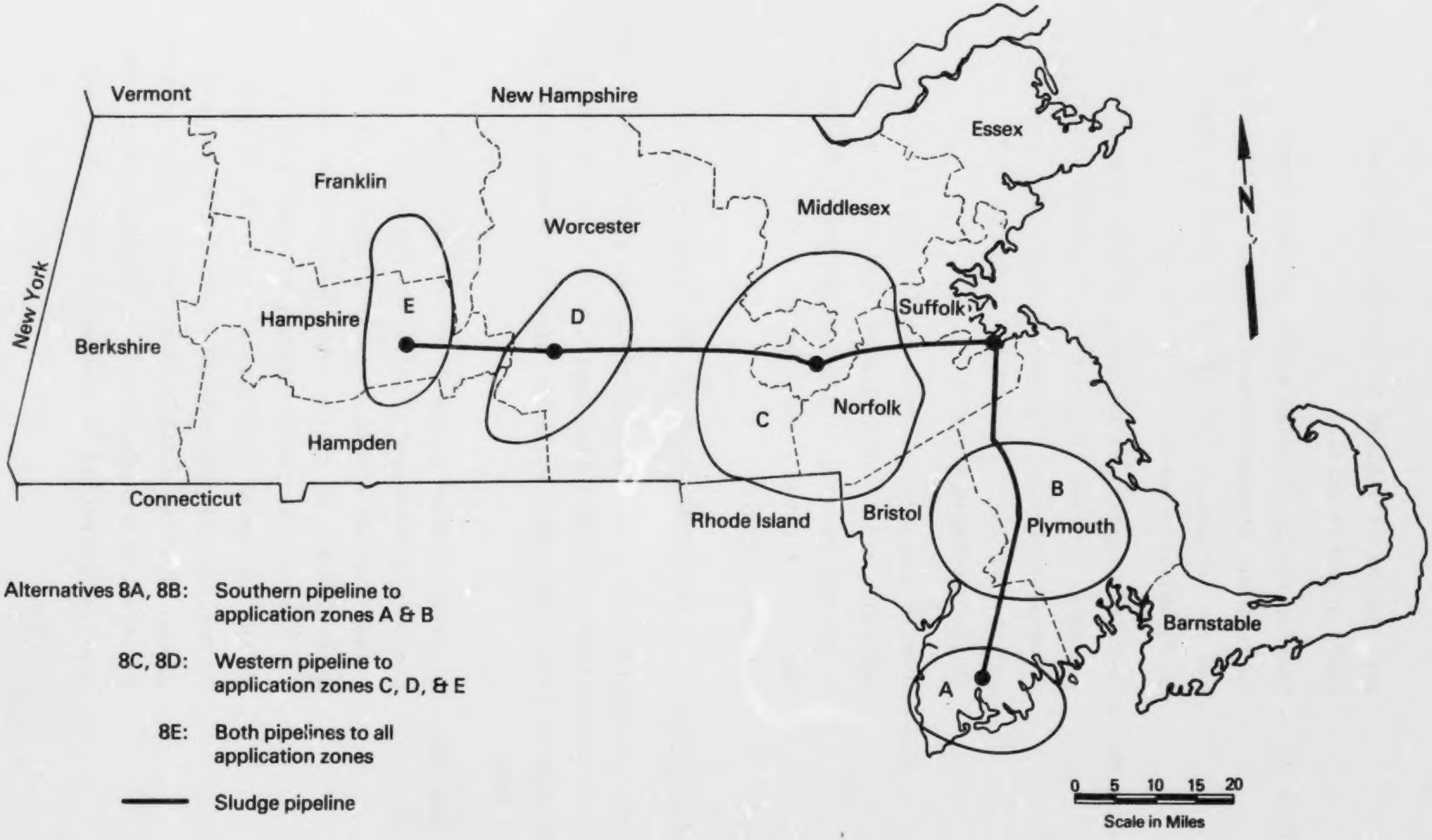
Case 7A -- no sludge is composted. Digested primary sludge at Deer Island and Nut Island are separately dewatered and barged to Mystic terminal. The sludge cake is trucked to landfill in Plainville. No capital or O&M costs are included for composting.

Case 7B -- same as Case 7A except Nut Island's digested sludge is pumped to Deer Island for combined dewatering prior to landfill.

Alternative 8 -- Land Application at Dispersed Sites

Anaerobically digested sludge from Deer Island would be pumped via submerged pipeline to Nut Island and combined with anaerobically digested sludge from Nut Island. The combined sludge would be pumped as a liquid slurry to remote regional storage/transfer sites. Sludge would be transported in tank trucks to dispersed, privately owned farms. At the farm, the liquid sludge would be incorporated into the soil via subsurface injection. 4380 acres are required in each case, not including any buffers. Figure 3.2-2 shows the location of the land application areas.

Case 8A -- 53-mile sludge pipeline along southern route; sludge is trucked from regional transfer points to on-site storage lagoons throughout the year;


Vermont
New Hampshire
New York
Essex
Franklin
Worcester
Middlesex
Berkshire
Hampshire
E
D
Suffolk
C
Norfolk
Hampden
Connecticut
Rhode Island
Bristol
B
Plymouth
Barnstable
A
N
0 5 10 15 20
Scale in Miles

Alternatives 8A, 8B: Southern pipeline to application zones A & B

8C, 8D: Western pipeline to application zones C, D, & E

8E: Both pipelines to all application zones

— Sludge pipeline

(From EPA Draft EIS)

application is limited to 120 days per year. (6400 suitable acres.)

Case 8B -- 53-mile sludge pipeline along southern route to regional storage lagoons, sludge distribution and application is limited to 60 days per year. (6400 suitable acres.)

Case 8C -- 76-mile sludge pipeline along western route, sludge is trucked from regional transfer points to on-site storage lagoons throughout the year, application is limited to 120 days per year. (19,160 suitable acres.)

Case 8D -- 76-mile sludge pipeline (53 miles along the southern route and 75 along the western route) to regional storage lagoons, sludge distribution and application is limited to 60 days per year. (25,560 suitable acres.)

Alternative 9 -- Land Application at MDC Owned Sites

This alternative involves the transportation of digested primary sludge to centralized, MDC-owned land application sites in the Plymouth/Sandwich area. The sites would be farmed to produce corn for animal feed.

Case 9A -- digested primary sludge from Deer Island would be pumped via submerged pipeline to Nut Island. Deer Island and Nut Island digested primary sludge at approximately 5% solids would be pumped 53 miles via buried pipeline to central storage lagoons at two MDC owned application sites. Sludge would be transported from storage to fields by an underground pipeline distribution system. Sludge would be injected into the fields by Milbord plows. The application period is assumed to be 120 days per year. The land requirement would be 5040 acres including buffer areas. The application rate would be 10 dry tons per acre per year.

Case 9B -- same as Case 9A, except application is limited to 60 days per year, increasing the loading rate for the application period, though keeping the annual total of 10 dry tons per acre.

Case 9C -- digested primary sludge from Nut Island would be pumped via submerged pipeline to Deer Island. The combined sludge would be chemically conditioned and vacuum filtered at Deer Island and loaded into barges. The dewatered sludge at about 25% solids would be barged 50 miles to an existing terminal facility at Sandwich. From Sandwich, the sludge would be trucked 5 or 20 miles to one of two MDC application sites where the sludge cake would be stored in sheds. The sludge would be applied 120 days per year by Big Wheel dry spreaders. The land requirement would be 3600 acres, including buffer zone. The application rate would be 15 dry tons per acre per year.

Case 9D -- same as Case 9C, except application is limited to 60 days per year.

3.3 Economic Analysis of Alternatives

Table 3.3-1 shows the costs for each of the cases described in the preceding section. All capital costs are based on an ENR Cost Index of 2200, as used in the EMMA study. The capital cost for each alternative is converted into annual payments,* and a total cost for the system computed by adding constant annual O&M. Revenues are then

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*Annual costs of capital are calculated by use of the appropriate capital recovery factor at an annual interest rate of 7% for the expected service life in years for each major capital cost item included in the capital cost summaries (see Appendix 3A).

Table 3.3-1

SUMMARY COST COMPARISONS OF ALTERNATIVES

(Basis: 1985 Average Daily Sludge Production)

Type	Case	Capital Cost ($1000) (ENR2200)	Annual Cost ($1000/yr.)		Total	Revenue ($1000/yr.)	Net Annual Cost ($1000/yr.)	Unit Cost $/dry ton[1]	Unit Cost to MDC $/dry ton[3]
			Capital	O&M					
Incineration	1A	29,007	2,544	2,476	5,020	402	4,618	105.87	53.38
	1B	29,644	2,604	2,354	4,958	332	4,626	106.06	52.33
	1C	29,644	2,604	2,652	5,256	388	4,868	111.61	57.87
	1D	29,644	2,604	3,132	5,736	444	5,292	121.33	67.59
Pyrolysis	2A	30,044	2,642	2,626	5,268	486	4,782	109.63	55.12
	2B	30,044	2,642	3,076	5,718	681	5,037	115.48	60.96
	2C	30,044	2,642	3,991	6,633	891	5,742	131.64	77.13
Co-combustion[2]	3A	15,531	1,435	2,682	4,117	284	3,833	87.88	65.52
	3B	10,150	**891**	3,655	4,546	495	4,051	92.88	75.47
Ocean discharge	4A	3,070	279	477	756	0	756	17.33	11.58
	4B	16,726	1,233	283	1,516	0	1,516	34.76	9.31
Ocean dumping	5A	10,535	964	1,280	2,244	0	2,244	51.45	31.55
	5B	10,535	964	1,591	2,555	0	2,555	58.58	38.68
	5C	16,161	1,365	1,330	2,695	0	2,695	61.79	33.62
	5D	16,161	1,365	1,641	3,006	0	3,006	68.92	40.75
Composting	6A	19,173	1,717	2,316	4,003	0	4,033	92.46	57.03
	6B	20,162	1,797	3,162	4,959	0	4,959	113.69	76.61
Landfill	7A	10,535	964	3,826	4,790	0	4,790	109.82	89.92
	7B	16,161	1,365	4,005	5,370	0	5,370	123.12	94.95
Land application (dispersed) **Private Sites**	8A	21,568	1,970	1,322	3,292	0	3,292	75.47	34.82
	8B	31,365	3,782	1,669	5,451	0	5,451	124.97	46.93
	8C	25,618	2,264	1,436	3,700	0	3,700	84.83	38.11
	8D	35,415	4,075	1,783	5,858	0	5,858	134.30	50.22
	8E	**44,915**	**4,745**	**1,975**	**6,720**	**0**	**6,720**	**153.65**	**56.11**
Land application (dispersed) **MDC Sites**	9A	39,608	2,954	784	3,738	350	**3,388**	77.68	16.72
	9B	41,679	3,152	805	3,957	350	3,607	82.70	17.66
	9C	31,341	2,674	3,543	6,217	250	5,967	136.80	81.62
	9D	32,241	2,841	3,842	6,683	250	6,433	**147.49**	88.86

[1] Based on 119.5 dry tons per day of digested primary sludge.

[2] Incremental sludge costs over and above a solid waste facility with capital costs of $36,108,500, annual O&M costs of $3,713,000, and annual revenues of $5,503,000.

[3] Assuming 100% eligibility of capital expenditures except co-incineration.

subtracted to give a net annual cost, or a unit cost in $/dry ton produced each day.

Incineration: the incineration alternatives range from a minimum cost of about $106/ton to a maximum of $121/ton, depending on the effectiveness of sludge drying and the excess air and fuel requirements. Assuming 100% grant eligibility, and the Massachusetts state contribution of 15% of all capital cost, the MDC will cover 10% of the capital cost, all of the O&M costs, and receive all revenues. For the incineration alternatives, the residual payment by the MDC will range from $52 to $68 per dry ton.

Pyrolysis: costs are slightly higher than incineration (though air quality should be slightly better: see section 3.4), ranging across equivalent alternatives from $110/ton to $132/ton. Of this, about $55 to $77/ton would be local costs.

Co-combustion: significantly less expensive than the other combustion alternatives. However, it appears unlikely that the system would be grant eligible except for dewatering and barge facilities, so that the full cost of $80-$85/ton would only be reduced to $65-$75/ton borne by the MDC, and the ultimate local costs for co-incineration are as high as those for incineration or pyrolysis.

Ocean Discharge: the ocean discharge alternative is the least expensive of all options, on the order of $17 to $35 per dry ton, with local costs of $9 to $11 per dry ton. It is a low O&M alternative, since it simply requires pumping the wet sludge to a discharge point, with minor maintenance on the pipe. For close-in discharge, it was assumed that the electron beam irradiation system developed for NSF at Deer Island would be used on the sludge to mitigate the problem of pathogen discharge in Boston Harbor. This is not currently required, and removing it would reduce the costs of this inexpensive alternative even further.

Ocean Dumping: this option is much more expensive than ocean discharge for both near (30 mile) and far (70 mile) dumping points. The incremental cost of adding 40 miles of travel are only about $7/ton, and the total system costs range from $51 to $70/ton, with local shares of $31 to $41 per ton. For this alternative, separate handling of Deer and Nut Island sludges would save about $10/ton.

Composting: the two composting alternatives show a range of costs, from $92 to $114/ton. In the first, everything goes right; in the second, the composting system has to be protected from the weather, the price of wood chips rises, and only half of the compost can be given away (the rest is landfilled). A real compost system would probably show performance between these two extremes.

Landfill: is a surprisingly expensive option, costing $110 to $123 per ton, with local costs extremely high at $90 to $95/ton. Dewatering is required, there are high trucking expenses and significant fees at the landfill itself. Since most of these costs are O&M related, the cost to the MDC would also be high.

Land Application at Dispersed Sites: this alternative involves distribution of sludge for use on cropland, by individual arrangements with farmers in the area. It is assumed that the sludge is accepted at no charge by the farms, but also that no revenue is received from the sludge. Wet sludge is used, and is piped either south (limited acreage available), west (more acreage, but further away), or in both directions (maximizing acreage). The range in costs is from $75/ton to $164/ton. The premium for using the western route over the southern is only $10/ton; much more significant is the effect on storage and transportation of the length of the application season: with 120 days for application, the southern route cost is $75/ton; with only 60 days, it is $225/ton. Most of these expenses are capital, however: MDC costs range from $35/ton to $62/ton for all system variations.

The land application at dispersed sites alternative shows the highest range in costs (and, implicitly, the highest economic risk) of any of the alternatives.

Land Application at MDC Sites: this alternative assumes that the MDC is willing to enter the farming business (see 3.4), and also shows a significant range in costs, from $78 to $147/ton. Here, however, the major difference is a technical one associated with transportation mode: the costs when piping is used seem to be about $80/ton, while the costs when dewatering and barging are used are about $140/ton. Local costs also vary significantly, with the pipeline system running about $11/ton, and the barge system costing over $80/ton to the MDC.

3.3.1 Local Impacts of the Costs

The costs of sludge handling, particularly for primary sludge, are only a small portion of all wastewater costs. As described in Appendix 3B, local costs were computed for a number of system combinations using three communities as typical examples: Boston, the central city of the region; Malden, an older developed suburb with sewers; and Weston, a bedroom suburb which may sewer and join the MDC, or may not. Table 3.3-2 shows the annual costs of several of the sludge alternatives in dollars per household and $/1000 gallons of industrial flow to each community.*

These costs of $2, $3, or even $4 per household annually are not going to cause major hardships, except as they are part of the complete costs of a wastewater system. There are three other major components to wastewater system charges:

- current costs of the MDC system (particularly continuing debts)
- costs to be incurred in building the EMMA plan or alternatives
- local systems costs

As described in the Appendix, these costs were computed from (1) MDC records; (2) the Kennedy Engineers early work; and (3) the EPA 1976

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*Weston household costs are low because they are averaged over connected and unconnected households.

Table 3.3-2

ESTIMATED LOCAL SLUDGE MANAGEMENT ASSESSMENTS

	$/household (annually)			$/1000 gallons Industrial Flow		
Case	Boston	Malden	Weston	Boston	Malden	Weston
Incineration (1A)	2.45	2.30	.12	.046	.046	.043
Pyrolysis (2B)	2.96	2.78	.15	.052	.053	.048
Co-Combustion (3A)	3.18	2.99	.16	.056	.057	.052
Ocean Disposal (4B)	.43	.41	.03	.014	.014	.013
Ocean Dumping (5B)	1.76	1.66	.09	.027	.027	.026
Composting (6B)	3.49	3.27	.17	.054	.054	.053
Landfill (7A)	4.08	3.84	.29	.056	.056	.054
Land-dispersed						
South (8B)	2.17	2.04	.13	.042	.042	.038
West (8C)	1.76	1.65	.09	.035	.035	.037
Land -- MDC (9B)	.85	.79	.06	.032	.032	.029
(9C)	3.73	3.50	.17	.063	.063	.059

Needs survey on a town by town basis.* The basic EMMA alternative costs about $40/household per year in toto for Boston; sludge management adds another $2 or so, amounting to 5-10% of the annual payments by households. The range, however, is significant: Kennedy alternative 1A (upgrading of the existing system) plus continued ocean disposal of sludge, will cost the average Boston household $18.46 in 1985, using constant 1975 dollars. The EMMA recommended plan, plus incineration of sludge and assuming the same local activity, costs the average household in Boston $43.86 annually. The impact of primary sludge management on these costs is only a few percent, even though large sums are expended on sludge. The EMMA plan without secondary treatment is in between, at about $32/household annually.

A further analysis of financial impacts for the full system, and for particular case study communities will be contained in the USR&E institutional report; for the purposes of this section, it is sufficient to say that any of the primary sludge management alternatives would have a relatively small impact on total system burdens on households. Local cost burdens for primary sludge management are relatively small, compared to the costs of the rest of the system.

3.4 Environmental Emissions of Sludge Alternatives

Each of the overall sludge options -- combustion, ocean disposal, and land application -- has characteristically different emissions from the others. The concern of the national planner is to trade-off among media, and to develop procedures for ranking each option according to its overall environmental risk. This is the process which generates standards, and it needs continuing local research and experience to make the standards realistic.

The local planner sees a completely different set of issues. In one form of local sludge management, the planner is interested in

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*Plus the Weston Facilities plan.

"finding something to do with the stuff." His or her concern is simply to identify an acceptable alternative; if there are several alternatives, relative environmental risks and benefits are assessed along with costs and other impacts, and a decision is made among them. Another form of local sludge planning, illustrated by Chicago's Metropolitan Sanitary District, is to make a committment to resource use and attempt to do "what is right" independent of federal funds or regulations. It is unfortunate that this approach is uncommon, but it is also clear that municipalities which take their own initiatives run significant risks.

Therefore, it is the former view of the world which is taken in this section. It is assumed that federal regulations exist, and that the planner must evaluate environmental impacts according to whether they require invoking the standards. Emissions and the related standards are assumed to be more significant initially than ambient quality, since they act as constraints. This allows estimation of, in Section 4, the impact on local planning of setting and changing standards. For the moment, however, two assumptions about sludge planning are made:

- The MDC must choose an alternative which is allowed under federal regulations
- The MDC has the ability to implement any such alternative*

Tables 3.4-1 to 3.4-5 show the major emissions from the various sludge options, and some of the relevant standards. Table 3.4-6 then summarizes these data for the various alternatives. It is apparent from current experience that sludge incinerators and pyrolysis systems can meet the New Source Performance Standards for such facilities,

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*See section 3.5 for further consideration of this assumption.

Table 3.4-1

MAJOR ENVIRONMENTAL ISSUES FOR ALTERNATIVES

I. Combustion	particulates (offset required for co-incineration) odor potential NO_2 (major source, but the area is not currently non-attainment) ash in landfill volatilization of certain metals (particularly mercury)
II. Ocean	cadmium and other metals turbidity biota impacts
III. Landfill	capacity and barrier control
IV. Land Application and Composting	salt content metals pathogens

Table 3.4-2

MAJOR EMISSION ESTIMATES FOR ALTERNATIVES

Case	Mode	Item	Quantity
6A, 6B, 7A, 7B	In sludge	Cadmium	60 ppm, dry weight*
8A-8E	Applied	Cadmium	1.2 Kg/ha/year
9A, 9B	Applied	Cadmium	1.2 Kg/ha/year
9C, 9D	Applied	Cadmium	1.6 Kg/ha/year
1A-1E	Air	Total Suspended Particulates	1.3 lb/ton of dry sludge*
	Air	Mercury	79 grams/day*
2A-2C, 3A, 3B	Air	Total Suspended Particulates	1.3 lb/ton of dry sludge*
4A-4C, 5A-5D	Ocean	Metals	See table 2.2-7

*weighted compositions of Deer and Nut Islands

Table 3.4-3

EXISTING AIR EMISSION STANDARDS

Regulation	Parameter	Limit
U.S. EPA NSPS standard for sewage sludge incinerators[1]	Total Suspended Particulates Mercury	1.3 lb/dry ton input 3200 grams/24 hours
U.S. EPA emission offset requirements	Any regulated pollutant	(1) must meet lowest achievable emission rate, and (2) obtain more than equivalent offsetting emission reduction from existing sources
Massachusetts NSPS standard for municipal incinerators[4]	Particulates Mercury	.05 grams/dscf[2] 3200 grams/day[3]

[1] Also applies to pyrolysis of sewage sludge.

[2] dscf = dry standard cubic foot.

[3] May not be applicable.

[4] Applies to co-combustion options.

Table 3.4-4

EXISTING OCEAN DISPOSAL CRITERIA*

(Federal Register 1-11-77)

Mercury (and its compounds)	
Solid Phase	<0.75 mg/kg
Cadmium (and its compounds)	
Solid Phase	<0.6 mg/kg
Organohalogens	$\leq$0.01 of the acute toxicity measured by bioassay
Oil and Greases	1 part waste to 100 parts water added in undisturbed water produces no visible surface sheen

*These criteria will not be applicable after acceptable bioassay procedures are published in the Federal Register. The criteria will then be based on bioassay results which "do not indicate occurrence of significant mortality or significant adverse sublethal effects."

Table 3.4-5

SUMMARY OF EXISTING AND PROPOSED GUIDELINES ON CADMIUM FOR LAND APPLICATION OF SLUDGE TO FOOD CHAIN CROPS

Location	Type of Guideline	Annual Limit	Cumulative Limit	Other
U.S. EPA	Recommendation	1 Kg/ha/yr (to 1985) 0.5 Kg/ha/yr (1985 on)	5 Kg/ha @CEC<5 10 Kg/ha @CEC=5-15 20Kg/ha@CEC>20	no leafy vegetables, root crops or tobacco
U.S. Food and Drug Administration	Recommendation	---	10 Kg/ha where CEC=5-15	maximum concentration in applied waste = 20 ppm (dry)
U.S. Department of Agriculture	Recommendation	1 Kg/ha/yr - liquid sludge 2 Kg/ha/yr - dewatered sludge	---	---
California	Proposed Regulation	.33 Kg/ha/yr		
Colorado	Proposed Regulation	---	---	monitoring after 5 years
Delaware	Proposed Regulation	.51/Kg/ha/yr (to 1981) .38/Kg/ha/yr (1982-1986) .26/Kg/ha/yr (1986-)		
Illinois	Proposed Regulation	2.25/Kg/ha/yr	11.2 Kg/ha/yr @ CEC=5-15	
Maryland	Regulation	1.12/Kg/ha/yr		
New Jersey	Interim Guidelines	---	5.0 Kg/ha 20.0 Kg/ha	CEC 0-15 CEC 5-15

Table 3.4-5

SUMMARY OF EXISTING AND PROPOSED GUIDELINES ON CADMIUM FOR LAND APPLICATION OF SLUDGE

(continued)

Location	Type of Guideline	Annual Limit	Cumulative Limit	Other
Ohio	Recommended Guidelines	---	5 Kg/ha	CEC 0-5
		---	10 Kg/ha	CEC 5-15
		---	20 Kg/ha	CEC >15
Pennsylvania	Proposed Regulation	1.12/Kg/ha/yr	3.37/Kg/ha	
Vermont	Proposed Regulation	---	---	maximum concentration in applied sludge = 15 μg/g (dry)
Wisconsin	Regulation	2.25/Kg/ha/yr	22.46/Kg/ha	maximum concentration in applied sludge = 25 ppm (dry)
Sweden		.015 Kg/ha/yr	.075 Kg/ha	
Ontario		---	1.57 Kg/ha	
Great Britain		1.12 Kg/ha/yr	5.0 Kg/ha	

TABLE 3.4-6

COMPARISON OF MAJOR EMISSIONS AND STANDARDS

Alternative	Item	Emission	Standard	Rating
Incineration 1A to 1E	TSP Mercury	1.3 lb/ton 79 g/day	1.3 lb/ton 3200 g/day	Acceptable Acceptable
Pyrolysis 2A to 2C	TSP	1.3 lb/ton	1.3 lb/ton	Acceptable
Co-Combustion 3A, 3B	TSP	1.3 lb/ton	1.3 lb/ton	Acceptable
Ocean Discharge 4A, 4B	Cadmium Mercury	60 ppm 6 ppm	unknown* unknown*	Probably Unacceptable Probably Unacceptable
Ocean Dumping 5A, 5E	Cadmium Mercury	60 ppm 6 ppm	.6 ppm .75 ppm	Unacceptable Unacceptable
Composting 6A, 6B	Cadmium (concentration)	60 ppm	20 ppm **	?
Landfill 7A, 7B	Cadmium (Concentration)	60 ppm	--	Acceptable
Land Application at Private Site (8A to 8E) or MDC Site (9A to 9D)	Cadmium (Concentration)	1.2Kg/ha/year	1.0 Kg/ha/yr to 1985*** .5 Kg/ha/yr 1995+	?

*Standards apply to ocean dumping only

**FDA recommendation for maximum applied concentration; not existing standards

***EPA recommendation; no existing standards and that the combustion alternatives are environmentally acceptable under the current regulations. There is a major cost to meeting these standards, but that economic risk is included in the cost analysis already. There is some concern that sludge incinerators may fall under the emission offset policy for NO_2, and co-incineration facilities would be major sources, requiring particulates offset as well. In addition, future secondary sludge incineration would require offsets for several categories. However, the offset policy does not eliminate facilities, and it appears that the combustion alternatives could be built. In general, incinerators can meet air pollution standards: the costs of operation may rise, but the limits can be achieved.

There is some concern with incineration and pyrolysis about ash landfill, and the quality of barriers receiving water from runoff and leaching. The EPA has assumed that such a barrier could not be developed at Deer Island. The ash could be transported to other sites such as Plainville, increasing costs somewhat, but not eliminating combustion alternatives from consideration.

The situation is the reverse with ocean dumping and discharge alternatives. Under current legislation, ocean dumping in 1985 is impossible. Ocean discharge is slightly more likely to be allowed, but it appears that the sludge would have to meet secondary treatment (30-30) requirements in its permit, which is, at the least, unlikely. Thus, the ocean alternatives do not currently exist, because of environmental standards.

The land alternatives fall between these two extremes. Landfill is possible, though capacity may be a problem (see Section 4). It is assumed that landfills of the required standards will be permitted by Massachusetts, and that the option of landfilling is available.

Composting does not seem to lead to any particular environmental problems at Deer Island; however, the metals loadings of Deer Island compost may make it unsuitable for give-away to the home gardener. The use of compost for non-food chain uses such as turf production and parkland improvement would not create a public health problem. Parkland on turf farming applications are acceptable, and have been assumed. Salt, metals, and pathogens form the basic environmental problems for land utilization of sludge in general, and standards are not available at this time, though they will be developed soon.

The land application alternatives affecting food chain crops are in transition. The proposed alternatives may be allowed by EPA when standards are promulgated, but they may not.* The risk of building a facility and then being unable to use it because of standards stricter than expected (or of overbuilding, and having high costs to meet standards higher than necessary) are extreme in the land application area.

In sum, the combustion alternatives and composting are allowed at this time, and can be built to meet the current regulations (transforming environmental risks to economic ones). The ocean alternatives will soon be unavailable. Landfill can probably be used, assuming landfills meet the RCRA criteria being developed, and land application to the food chain is allowable, but subject to major changes in standards in the near future. This is the local perspective on the environmental aspects of sludge handling: it is a perspective based on feasibility, at least in the first stage of the analysis.

3.5 Institutional Factors Affecting Implementation

There is no doubt that the MDC has the powers and authority to implement the incineration or pyrolysis alternatives. They are able to construct and operate wastewater treatment facilities on their own land, given approval of financing, and there are no major institutional constraints on these alternatives. Staffing limitations and other factors affecting their ability to operate complex systems effectively may be significant, however. Some of these issues are discussed in the Kennedy Engineers report (1977) and the USR&E study (1977).

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*For example, EPA's long awaited Technical Bulletin on land application of wastewater sludges finally appeared in November 1977.

Similarly, there is little doubt that the MDC could continue use of ocean discharge or convert to ocean dumping (if allowable). These two options require little additional expertise, and no additional authority for the agency. As with all the other options, they require state approval of financing, but this is true everywhere, and we have assumed that it is possible. Use of landfill would also be straightforward, assuming significant capacity was available in private sites, with which contracts could be negotiated for primary sludge disposal.

Therefore, the major institutional limits arise with respect to co-combustion and the land options: composting, dispersed site land application, or land application at MDC-owned sites. The major co-combustion issue, discussed in some depth in the Stone & Webster report,[2] is finding a firm or agency to develop the incinerator. The Commonwealth has supported private development of regional resource recovery facilities, and this appears the most attractive option, but sludge would only be a portion of the wastes, and the facility depends more on committments of sufficient solid waste than it does on sludge availability. The ability of the MDC to enter into the solid waste disposal field is unclear.

The remaining options involve utilization of the sludge on land, and this has been our major area of institutional analysis, as discussed below.

3.5.1 Current State Policy on Land Application

Although land application has not been viewed in the past as a favored method of disposal in Massachusetts, the technique is now receiving close attention and a preliminary state policy on it has been developed. The state's position on surface application of sludge is set forth in a letter written by Commissioner Standley of the Department of Environmental Quality Engineering (DEQE) to the Chicago engineering firm of Greeley and Hansen on August 19, 1977 (see Appendix 5A).

Commissioner Standley's letter states, in effect, that sludge application may be permitted on a case-by-case basis in Massachusetts if certain safeguards are observed. Two major conditions are specified for application on agricultural land:

(1) If the sludge conforms to appropriate nitrogen and heavy metal limits, then liquid sludge may be applied by injection and dewatered sludge may be ploughed or harrowed into the land.

(2) Surface application of dewatered sludge may be permitted if the sludge has been subjected to composting or heat treatment, presumably in order to destroy pathogens contained in the wastes.

Sludge application will also be considered on non-agricultural lands. No threshold conditions are specified in the DEQE letter, but it may be presumed that fewer restrictions will attach to surface disposal on lands that are not used for growing crops.

Beyond this, the letter indicates that the subject of land application is now under active study by the Legislature and by a specially designated "commission." Lack of interest among concerned state agencies is thus not a real obstacle to widespread use of land application. More significant is the need for a regulatory program that goes beyond the minimal guidance provided by the DEQE letter and specifies in detail the technical and procedural requirements that must be met in a land application project. It also becomes important to determine whether MDC or another suitable agency can gain access to sufficiently large tracts of agricultural land for purposes of sludge application.

3.5.2 Possible Regulatory Structures for Promoting Land Application

While Commissioner Standley's letter shows that the state is tolerating and even encouraging individual experiments in land application of sludge, the regulatory mechanism needed to promote effective sludge management on a statewide basis is not yet in place. In this section we review existing regulatory schemes and institutional arrangements that could most easily accommodate a comprehensive program of land application. An appropriate structure for promoting and regulating sludge application must be identified before this disposal strategy can be regarded as a serious alternative to incineration and landfilling.

The Hazardous Waste Disposal Program

The Massachusetts hazardous waste disposal program, organized under authority of 21 M.G.L. §§57,58, contains most of the elements needed to construct an effective land application program. 21 M.G.L. §57 assigns to the state Water Resources Commission (WRC) the responsibility for regulating the handling and disposal of hazardous wastes. The WRC is an inter-departmental agency whose members include the Commissioners of Food and Agriculture, Commerce and Development, MDC, Environmental Management, Environmental Quality Engineering, and Fisheries and Wildlife.* The WRC thus brings under one organizational umbrella every environmental and economic interest of the state that is likely to be affected by a program for applying sludge on land.

Acting as a board to regulate disposal of chemical and other hazardous wastes, the WRC has the authority to promulgate any rules and regulations that are necessary to protect the public or the environment from the effects of such waste. Administration of these regulations may be delegated to the most appropriate agency represented on the board. In practice, the licensing procedure prescribed by 21 M.G.L. §58 probably provides the most efficient means of enforcing the board's regulations.

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*20 M.G.L. §8.

Disposal of hazardous wastes in Massachusetts requires a license from the Division of Water Pollution Control (DWPC), a regulatory arrangement that makes good sense from the standpoint of land application of sludge. DWPC is familiar with the problems of sludge management through its involvement in facilities planning for individual treatment plants. Moreover, the Division is particularly well equipped to evaluate the potential impact of sludge disposal on water quality. DWPC may condition issuance of a license on prior approval by one or more of the other agencies represented on the hazardous waste disposal board. This procedural device allows DWPC to obtain expert evaluation of aspects of the project that the Division itself lacks competence to review.

Analysis of the regulations issued by the WRC pursuant to 21 M.G.L. §57* suggests that, though they were not drafted with specific attention to the problems of sludge disposal, they could, with only minor revision, provide a framework for regulating land application. It does not appear, for example, that these regulations were designed to exclude sludge from the reach of the hazardous waste program, although this point cannot be clarified definitively through textual analysis.** The scope of regulation does not extend to residual wastes contained in "discharges from an appropriate and properly operating waste treatment facility, pretreatment facility or other facility complying with a State or Federal discharge permit or license or numerical effluent standard."* But this exclusion clearly does not refer to wastes removed from wastewater in the form of sludge before the treated water is discharged into receiving waters. More troublesome is the statement that "the scope also specifically excludes transportation and disposal of municipal refuse, sewage sludge and demolition materials which are subject to regulation under separate authority within the General Laws" (emphasis added).** If this ambiguously worded exemption is read as applying to sewage sludge only to the extent that it is already regulated under separate legal authority, then there is no inconsistency in applying the hazardous waste regulations to control sludge application on land surfaces. While disposal of sludge in conventional sanitary landfills can be regulated through the solid waste program, the General Laws seem to contain no specific authority for regulating the recycling of sewage sludge onto farm lands in the form of fertilizer.

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*Water Resources Commission -- Division of Water Pollution Control, Board of Chemical and Other Hazardous Wastes Regulations (January 11, 1973).

** Hazardous wastes are defined in Regulation 2.1 of the Hazardous Waste Regulations as "waste substances which, because of their chemical, radioactive, flammable, explosive or other characteristics, constitute or may reasonably be expected to constitute a danger to the public health, safety or welfare or to the environment." Sludges, because of their industrial waste content, may constitute a hazard to health if not properly disposed of, and hence may properly be regulated through the hazardous waste program. So-called "infectious wastes" are excluded from regulation under 21 M.G.L. §57, but this exclusion refers to hospital wastes and not to sludge containing small quantities of pathogens.

The hazardous waste regulations expressly provide for control of metallic wastes. Regulation 4.0 establishes a category of "toxic metals, etchants, pickling and plating wastes" in its classification of hazardous wastes. Materials classified under this heading include "aqueous solutions and sludges containing cyanide, or toxic metals."† To date, DWPC has not interpreted this category broadly enough to include sewage sludge containing toxic metals, mainly because the agency believes it does not have the resources to tackle the massive problems of sludge disposal. There is no indication, however, that DWPC considers itself to be without legal authority to regulate sludge through the hazardous waste program.

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*Hazardous Waste Regulations, op. cit., Regulation 1.0.

**Ibid.

†Ibid., Regulation 4.3

The Solid Waste Disposal Program

The state solid waste disposal program, as presently structured, does not seem to govern sludge application to land surfaces. 111 M.G.L. §150A furnishes the principal statutory authority for regulating the siting, operation and maintenance of refuse disposal facilities. A "facility," for purposes of this section, means "a sanitary landfill, a refuse transfer station, a refuse incinerator...a refuse composting plant, a dumping ground for refuse or any other works for treating or disposing of refuse." * Broad though this definition is, it would be stretched unreasonably far if every piece of land on which sludge is applied came to be regarded as a refuse disposal facility. In the context of land application, sludge is no longer simply "refuse," and the site on which it is applied cannot realistically be viewed as a disposal facility for spent wastes.

It would probably require a statutory amendment to bring land application within the jurisdiction of the solid waste program, which is administered in regulatory aspects by the Division of Air and Hazardous Materials within the Department of Environmental Quality Engineering. Through DEQE, that division also has a voice in the affairs of the Water Resources Commission and is thus well placed to participate in inter-departmental programs as well.

Of course, sludge disposal by means of conventional sanitary landfill already is regulated through the solid waste disposal program. Sewage sludge is classified by regulation as a "special waste" and is subject to stricter disposal procedures than ordinary solid wastes.

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*See Department of Public Health, Regulations for the Disposal of Solid Wastes by Sanitary Landfill, Regulations 1.16 and 16 (April 21, 1971).

Department of Food and Agriculture

The Department of Food and Agriculture has an obvious interest in the application of sludge to agricultural lands, but does not at present have the authority to regulate this activity. Situated within the Executive Office of Environmental Affairs, the department can fairly easily be drawn into interdepartmental arrangements, in an advisory capacity, with other agencies that have an interest in land application. As a member of the Water Resources Commission, the department can also influence licensing and other regulatory policies if land application is ever brought within the sphere of the program for hazardous waste disposal. For example, approval by the department could be made a condition precedent to obtaining a license from DWPC.

Independent action by the Food and Agriculture Department to promote or regulate land application does not seem likely in the near future. The department is not especially well qualified to manage large-scale farming operations involving application of sludge to crop lands. Its agricultural land use program seems to be designed primarily for the benefit of disadvantaged groups like the elderly and the poor.* On the regulatory side, however, since the transfer of the pesticide program back to Food and Agriculture, the department controls an apparatus that could perhaps be expanded so as also to meet the needs of a land application program. In particular, any expertise in monitoring pesticide application on crops or in soil and plant testing could prove extremely useful if the department is ever called upon to regulate sludge farming in Massachusetts.

The MDC as a Management Agency for Land Application

As a possible management agency for land application, the MDC lacks most of the powers commonly exercised by such agencies. It depends entirely on the state legislature for funding. It cannot issue revenue bonds or take property by eminent domain. It is worth inquiring whether an effective management role can be designed for the MDC in view of these gaps in its authority.

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*20 M.G.L. §§14, 15.

There is no question that it would be easiest to structure and implement a land application program if the MDC were endowed with all the powers of an agency like the Metropolitan Sanitary District of Greater Chicago. The Chicago MSD carries out extensive agricultural operations in Southern Illinois, using sludge from its own treatment facilities as fertilizer. The MSD owns the farmlands, contracts with labor unions to provide the requisite work force, and owns and supplies all the equipment needed for farm operations. Corn grown on MSD lands is sold as feed grain on the open market. The research and development branch of the MSD monitors the quality of MSD sludge and conducts plant testing to ensure that there is no contamination of crops from the application of sludge. Finally, the MSD enforces a set of pretreatment standards against industrial dischargers within its jurisdiction in order to control the metal levels in the wastewater received by its treatment facilities.

The contrast between the Chicago MSD and the MDC is impressive, but a successful program of land application does not require a concentration of the whole array of financial and regulatory powers possessed by the Chicago MSD within a single administrative agency. The MDC already owns and administers parklands to which composted sludge might be applied as a soil conditioner, without having to seek additional authorization and purchase money from the Legislature. This use of sludge, moreover, need not await formulation of the more elaborate safeguards that will be necessary to govern use of sludge on croplands. Once questions concerning potential harm to the environment have been settled, it should not be difficult for the MDC to obtain access to further public lands from other land-holding agencies (e.g., the Division of Forests and Parks within the Department of Environmental Management). The fact that these agencies are now located in the Executive Office of Environmental Affairs would facilitate any such inter-departmental arrangements. As long as sludge is clearly applied to promote conservation of the state's agricultural and silvicultural resources, the MDC's use of public lands for land application would not run up against Article 97 of the State Constitution, which prevents any change in use of public lands without explicit legislative authorization.*

It is unlikely that the MDC would have to go into the farming business itself in order to secure sludge application to croplands. 92 M.G.L. §82 authorizes the MDC to sell any real or personal property "no longer needed for the water works under its charge." This means that MDC sludge can be sold to private agricultural operators and perhaps applied on land under MDC supervision. It may be difficult to monitor application procedures and the effects of sludge on soil, water and plants when the farming operations are in private hands. But the danger of misapplication may be considerably reduced if the use of sludge on private farms is governed by an adequate set of DEQE regulations and if the MDC undertakes first to treat the sludge for removal of pathogens and to monitor its metal content.

3.5.3 Conclusion

Massachusetts does not as yet have any comprehensive program for sludge management, but the legal and institutional barriers to implementing such a program do not appear insurmountable. For purposes of this report, the most important point is that the state already recognizes land application as a potentially useful technique for sludge disposal and is taking steps to develop a firm policy on the subject. Commissioner Standley's letter on land application does not spell out the details of a regulatory program, but makes it clear that land application can gain DEQE approval if conducted in ways that do not endanger public health. Accordingly, the state's concern will focus on legitimate threats posed by metals and pathogens in the sludge.

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*Article 97, amending Article 49, provides, in pertinent part, that public lands "shall not be used for other purposes or otherwise disposed of except by a two-thirds vote...of each branch of the general court."

Despite limitations on its authority, the MDC is reasonably well situated to carry out certain non-agricultural land application programs. It can use some of its own lands for this purpose, supplemented by lands from other public sources (as in alternative 6). Additionally, the MDC may also find it convenient to promote land application by selling sludge to private farmers, rather than by engaging in agricultural operations itself (alternative 8). However, significant additions to the MDC's power would be required if it is to develop its own land application program. If land application is eventually administered through the hazardous waste program, MDC as a member of the Water Resources Commission will clearly have an important role in shaping the necessary regulations.

3.6 Tradeoffs and Evaluation

At this point, there are nine alternatives of varying cost. Five -- the incineration, pyrolysis, coincineration, composting* and landfill -- appear environmentally acceptable with respect to federal regulations. Two -- the ocean alternatives -- are unacceptable under current standards. Implementation of the remaining two -- land application at private sites and MDC land application -- is problematic: they may be possible under future regulations, but they may not. This is a particularly serious problem for the private site application option, since the agency would have less control over what happened with the sludge, and therefore less ability to adjust to changing regulations.

The ocean options, from the perspective of a person having to make a decision now, are not available. Cost and environmental tradeoffs among them are most. Both the land utilization and the combustion options, however, show very high risks to the agency. The former may be closed by standards to be issued (or, at least, may be changed significantly). The latter may not work as planned.

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*Assuming application to non-food chain areas.

There are real tradeoffs involved in deciding to choose one of the options which is federally acceptable. Incinerators of the proposed type have not been successfully operated. Pyrolysis, too, is untried in this country, but promises on theoretical grounds to provide lower emission rates and more stable operation than incineration. Its cost appears slightly higher, both nationally and to the MDC. Co-combustion is expensive to the MDC, and will result in higher particulate and other air pollution emissions close to the major activity centers of the area, but promises to be considerably cheaper on a national basis. Landfill appears likely to be the most expensive option of all locally, but would essentially relieve the agency of the problem, and would only increase air pollution in Boston by relatively small amounts of vehicle emissions. The land utilization options (besides landfill) show two disadvantages: they are generally new to the sanitary engineering profession and most of the planners involved, and they run the risk of significant design, operation, and cost changes as federal standards are issued and revised. Implementation issues such as finding the land, reorganizing the agency to be able to farm effectively, and the like may appear very difficult, as discussed above.

"Safe" Alternatives

A risk adverse local agency at this time would probably attempt to satisfy itself that one of the combustion options would work, because it appears that such a solution would be environmentally acceptable according to current and projected federal standards and relatively easy to implement and meet. Landfill and composting also would appear viable options. All these choices are relatively expensive, but that is the price paid at this point for certainty.

Land Application

The other local option is to choose land application, attempting to figure out upper bounds for the strictness of potential standards, and providing for them. Large investments, such as alternative 9 with MDC ownership of sites, or even alternative 8 with pipeline transportation, might not be wise. Instead, the rational agency in this situation might evaluate dewatering and barge transport in the short term, with sales to farmers if possible. Options providing increased flexibility in the decision process are discussed further in Section 4.

Table 3.5-1 shows some of the cost variations of interest, and the penalties being paid because of planning uncertainty about federal regulations. If it is assumed that each option can be built, the MDC would probably desire to choose incineration on a cost basis under the first group, land application at dispersed sites under the second, and ocean discharge under the third. These would lead to local costs of roughly \$53-\$68/ton for the "certain" option, \$34-\$62/ton for the "uncertain" and \$9-\$11/ton for the "unacceptable." In other words, the MDC would pay a penalty of \$23-\$53/ton or an expected value of \$1.7 million per year because of federal regulations against ocean discharge, and would pay an expected additional \$12/ton or \$500,000 per year because of the relative certainty that an incineration option would be federally acceptable. Similarly, the nation would expect to pay a penalty of about \$3.8 million per year to eliminate the ocean discharge option in Boston (comparing incineration with ocean discharge).

Local Choice

There are numerous other factors which would be considered in making a local choice. Most important is probably the judgment by

Table 3.5-1

COSTS OF ALTERNATIVES

	($/ton)	Local Cost ($/ton)
Group I: Acceptable Under Known Regulations		
1. Incineration	106 - 121	53 - 68
2. Pyrolysis	110 - 132	55 - 77
3. Co-incineration	88 - 93	65 - 75
6. Composting	92 - 114	57 - 77
7. Landfill	110 - 123	90 - 95
Group II: Relevant Regulations Being Prepared		
8. Land application - dispersed	75 - 154	34 - 56
9. Land application - MDC	78 - 147	17 - 89
Group III: Almost Certainly Unacceptable		
4. Ocean discharge	17 - 35	9 - 12
5. Ocean dumping	51 - 69	31 - 41

the MDC of whether an option could be implemented (see 3.5 above). The agency would also have to trade-off the significant impacts of each alternative against the others still being considered: is reducing air pollutants through composting worth $6/ton compared to incineration? is extra control over land application through the use of MDC-owned sites worth the extra variation in costs compared with dispersed sites? should the technical risk of pyrolysis be considered vis-a-vis incineration? and so forth. Since this study is not trying to prescribe which option Boston should choose, but instead only trying to lay out the options and assess the impacts of federal policies, these issues are not of concern here.

The potential benefits from further information are discussed in the sensitivity analysis. Section 3 was intended to set the stage, by showing some of the alternatives available at present, costs and emissions which might be expected from them, and the impact of current federal regulations on the feasible set. The actual choice of one (or more) alternatives should include more detailed analysis of the remaining options, and cover issues such as political feasibility (e.g., of a pipeline right-of-way) which were not our concern.

3.7 References

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APPENDIX 3-A

SUMMARY OF CAPITAL AND ANNUAL COSTS

TABLE 1

SUMMARY COST COMPARISON OF ALTERNATIVES

Case	Capital Cost (ENR 2200) ($000)	Annual Cost ($000/yr)			Revenue ($000/yr)	Net Annual Cost ($000)	Unit Cost $/dry ton*
		Capital	O&M	Total			
1A	29,007	2,544	2,476	5,020	402	4,618	105.87
1B	29,644	2,604	2,354	4,958	332	4,626	106.06
1C	29,644	2,544	2,652	5,256	338	4,868	111.61
1D	29,644	2,604	3,132	5,736	444	5,292	121.33
2A	30,044	2,642	2,626	5,268	486	4,782	109.63
2B	30,044	2,642	3,076	5,718	681	5,037	115.48
2C	30,044	2,642	3,991	6,633	891	5,742	131.64
3A	51,639	4,835	6,395	11,230	5,787	5,443	87.88**
3B	46,258	4,291	7,368	11,659	5,998	5,661	92.88**
3C	36,108	3,400	3,713	7,113	5,503	1,610	-
4A	3,070	279	477	756	0	756	17.33
4B	16,726	1,233	283	1,516	0	1,516	34.76
5A	10,535	964	1,280	2,244	0	2,244	51.45
5B	10,535	964	1,591	2,555	0	2,555	58.58
5C	16,161	1,365	1,330	2,695	0	2,695	61.79
5D	16,161	1,365	1,641	3,006	0	3,006	68.92
6A	19,173	1,717	2,316	4,033	0	4,033	92.46
6B	20,162	1,797	3,162	4,959	0	4,959	113.69
7A	10,535	964	3,826	4,790	0	4,790	109.82
7B	16,161	1,365	4,005	5,370	0	5,370	123.12
8A	21,568	1,970	1,322	3,292	0	3,292	75.47
8B	31,365	3,782	1,669	5,451	0	5,451	124.97
8C	25,618	2,264	1,436	3,700	0	3,700	84.83
8D	35,415	4,075	1,783	5,858	0	5,858	134.30
8E	44,915	4,745	1,975	6,720	0	6,720	153.65
9A	39,608	2,954	784	3,738	350	3,389	77.68
9B	41,679	3,152	805	3,957	350	3,607	82.70
9C	31,341	2,674	3,543	6,217	250	5,967	136.80
9D	32,241	2,841	3,842	6,683	250	6,433	147.49

*Basis: 119.5 dry tons per day of digested primary sludge solids.

**Calculated from incremented costs associated with sludge processing above costs for solid waste mono-treatment as in Case 3C.

TABLE 2

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 1 INCINERATION

	1A	1B	1C	1D	1E***
Fixed Costs:					
Capital cost (ENR 2200)	$29,007,000	$29,644,000	$29,644,000	$29,644,000	$30,044,000
Equivalent annual cost $/yr	$ 2,544,000	$ 2,604,000	$ 2,604,000	$ 2,604,000	$ 2,642,000
O&M Costs:					
Anaerobic digestion -					
dry ton/day	119.5	119.5	119.5	119.5	119.5
$/dry ton output	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
$/yr	$ 175,000	$ 175,000	$ 175,000	$ 175,000	$ 175,000
Sludge pumping -					
dry ton/day	45.5	45.5	45.5	45.5	45.5
$/dry ton	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00
$/yr	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000
Dewatering -					
dry ton/day	119.5	119.5	119.5	119.5	119.5
$/dry ton input	$ 25.00	$ 20.00	$ 20.00	$ 25.00	$ 20.00
$/yr	$ 1,090,000	$ 872,000	$ 872,000	$ 1,090,000	$ 872,000
Incineration -					
dry ton/day	127.5	127.5	127.5	127.5	127.5
$/dry ton input	$ 15.56	$ 17.62	$ 24.02	$ 29.65	$ 32.10
$/yr	$ 724,000	$ 820,000	$ 1,118,000	$ 1,380,000	$ 1,494,000
Ash disposal -					
dry ton/day	63	63	63	63	63
Barge & terminal (6.3 mi) $/ton ash	5.50	5.50	5.50	5.50	5.50
Truck haul (30 mi) $/ton ash	$ 6.50	$ 6.50	$ 6.50	$ 6.50	$ 6.50
Land fill $/ton ash	$ 7.00	$ 7.00	$ 7.00$	7.00	$ 7.00
Disposal $/yr	$ 437,000	$ 437,000	$ 437,000	$ 437,000	$ 437,000
Total Gross Annual Cost, $/yr	$ 5,020,000	$ 4,958,000	$ 5,256,000	$ 5,736,000	$ 5,670,000
Gross Unit Cost, $/dry ton*	$ 115.09	$ 113.67	$ 120.50	$ 131.51	$ 129.99
Annual Revenue:					
Power sales - Kw-hr/day**	$ 36,700	$ 30,300	$ 35,400	$ 40,500	$ 71,200
@ 0.03/Kw-hr	$ 402,000	$ 332,000	$ 388,000	$ 444,000	$ 780,000
Net Annual Cost $/yr	$ 4,618,000	$ 4,626,000	$ 4,868,000	$ 5,292,000	$ 4,890,000
Net Unit Cost $/dry ton*	$ 105.87	$ 106.06	$ 111.61	$ 121.33	$ 112.11

*Basis: 119.5 dry tons per day of digested primary sludge solids.

**Power sales at 87% use of average daily power production capacity.

*****Plus Afterburner: see chapter 4.**

TABLE 3

SUMMARY OF ANNUAL COSTS
ALTERNATIVE 2 PYROLYSIS

	2A	2B	2C
Fixed Costs:			
Capital cost (ENR 2200)	$30,044,000	$30,044,000	$30,044,000
Equivalent Annual Cost, $/yr	$ 2,642,000	$ 2,642,000	$ 2,642,000
O & M Costs:			
Anaerobic digestion - dry ton/day	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00
$/yr	$ 175,000	$ 175,000	$ 175,000
Sludge pumping - dry ton/day	45.5	45.5	45.5
$/dry ton	3.00	3.00	3.00
$/yr	$ 1,090,000	$ 872,000	$ 1,090,000
Dewatering - dry ton/day	119.5	119.5	119.5
$/dry ton input	25.00	20.00	20.00
$/yr	$ 1,090,000	$ 872,000	$ 1,090,000
Pyrolysis - dry ton/day	127.5	127.5	127.5
$/dry ton input	18.33	32.68	47.66
$/yr	$ 853,000	$ 1,521,000	$ 2,218,000
Ash disposal - dry ton/day	66	66	66
Barge & terminal fee $/dry ton	5.50	5.50	5.50
Truck haul $/dry ton	6.50	6.50	6.50
Landfill Fee $/dry ton	7.00	7.00	7.00
Disposal $/yr	$ 458,000	$ 458,000	$ 458,000
Total Gross Annual Cost, $/yr	$ 5,268,000	$ 5,718,000	$ 6,633,000
Gross Unit Cost, $/dry ton*	$ 120.78	$ 131.09	$ 152.07
Annual Revenues:			
Power sales - kw-hr/day**	44,400	62,200	81,400
@ $0.03/kw-hr	$ 486,000	$ 681,000	$ 891,000
Net Annual Cost $/yr	$ 4,782,000	$ 5,037,000	$ 5,742,000
Net Unit Cost $/dry ton	109.63	115.48	131.64

*Basis: 119.5 dry tons per day of digested primary sludge solids.

**Power sales at 87% utilization of average daily power production.

TABLE 4

SUMMARY OF ANNUAL COSTS
ALTERNATIVE 3 CODISPOSAL

	3A. Coincineration	3B Copyrolysis	3C Independent Solid Waste Incineration
Fixed Costs:			
Capital cost (ENR 2200)	$51,639,000	$46,258,000	$36,108,000
Equivalent Annual Cost, $/yr	$ 4,835,000	$ 4,291,000	$ 3,400,000
O & M Costs:			
Anaerobic digestion - dry tons/day	119.5	119.5	0
$/dry ton output	4.00	4.00	-
$/yr	$ 175,000	$ 175,000	0
Sludge dewatering - dry tons/day	119.5	119.5	0
$/dry ton input	20.00	20.00	-
$/yr	$ 872,000	$ 872,000	0
Sludge transport - dry ton/day	127.5	127.5	0
Barging & terminal fee - $/dry ton	13.86	13.86	-
Truck $/dry ton (3 mi)	3.00	3.00	-
Transport $/yr	$ 785,000	$ 785,000	0
Combustion - wet tons refuse/day	1500	1500	1500
- wet tons sludge/day	427	427	0
$/wet ton input	3.46	4.85	4.08
$/yr	$ 2,437,000	$ 3,410,000	$ 2,235,000
Residue disposal - dry ton/day	363	363	300
Truck $/ton (30 mi)	6.50	6.50	6.50
Land fill fee $/ton	7.00	7.00	7.00
Disposal $/Yr	$ 1,789,000	$ 1,789,000	$ 1,478,000
Total Gross Annual Cost, $/yr	$10,893,000	$11,322,000	$ 7,113,000
Gross Unit Cost, $/wet ton*	$ 15.49	$ 16.10	$ 10.11
Annual Revenue:			
Steam production (sat.250°F)-lbs/hr	371,000	330,000	350,000
@ $2/1000 lbs @ 75% utilization $/yr	$ 4,875,000	$ 4,336,000	$ 4,599,000
Ferrous metal sales - tons/day	105	105	105
@ $20/ton net, $/yr	$ 766,000	$ 766,000	$ 766,000
Aluminum sales - ton/day	0	7.5	0
@ $280/ton mat	0	$ 766,000	0
Water back charge	$ 146,000	$ 130,000	$ 138,000
Net Annual Cost $/yr	$ 5,106,000	$ 5,324,000	$ 1,610,000
Net Unit Cost $/wet ton*	$ 7.26	$ 7.57	$ 2.94

*Basis: 1500 TPD solid waste +427 TPD sludge cake = 1927 wet tons/day

TABLE 5

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 4 OCEAN DISCHARGE

	4A	4B	4C**
Fixed Costs:			
Capital cost (ENR 2200)	$3,070,000	$16,726,000	$18,356,000
Equivalent Annual Cost, $/yr	$ 279,000	$ 1,233,000	$ 1,387,000
O & M Costs:			
Anaerobic digestion - dry ton/day	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00
$/yr	$ 175,000	$ 175,000	$ 175,000
Sludge pumping			
Deer to Nut - dry ton/day	0	45.5	45.5
$/dry ton	-	3.00	3.00
$/yr	0	50,000	50,000
Pasteurization - dry ton/day	119.5	0	119.5
$/dry ton	5.60	-	5.60
$/yr	$ 244,000	0	244,000
Outfall - dry ton/day	119.5	119.5	119.5
$/dry ton	1.33	1.33	1.33
$/yr	$ 58,000	$ 58,000	$ 58,000
Total Annual Cost, $/yr	$ 756,000	$1,516,000	$1,914,000
Unit cost, $/dry ton*	17.33	34.76	44.88

*Basis: 119.5 dry tons per day of digested primary sludge solids.

**4B plus disinfection: See Section 4

TABLE 6

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 5 OCEAN DUMPING

	5A	5B	5C	5D
Fixed Costs:				
Capital cost (ENR 2200)	$10,535,000	$10,535,000	$16,161,000	$16,161,000
Equivalent Annual Cost, $/yr	$ 964,000	$ 964,000	$ 1,365,000	$ 1,365,000
O & M Costs:				
Anaerobic digestion-dry ton/day	119.5	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00	4.00
$/yr	$ 175,000	$ 175,000	$ 175,000	$ 175,000
Sludge pumping - dry ton/day	0	0	45.5	45.5
$/dry ton	-	-	3.00	3.00
$/yr	0	0	$ 50,000	$ 50,000
Dewatering - dry ton/day	119.5	119.5	119.5	119.5
$/dry ton input	20.00	25.00	20.00	25.00
$/yr	$ 872,000	$ 1,090,000	$ 872,000	$ 1,090,000
Disposal - dry ton/day	127.5	127.5	127.5	127.5
$/dry ton	5.00	7.00	5.00	7.00
$/yr	$ 233,000	$ 326,000	$ 233,000	$ 326,000
Total Annual Cost, $/yr	$ 2,244,000	$ 2,555,000	$ 2,695,000	$ 3,006,000
Unit cost, $/dry ton*	$ 51.45	$ 58.58	$ 61.79	$ 68.92

*Basis: 119.5 dry tons per day of digested primary sludge solids.

TABLE 7

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 6 & 7 COMPOSTING/LANDFILL

	6A	6B	7A	7B
Fixed Costs:				
Capital cost (ENR 2200)	$19,173,000	$20,162,000	$10,535,000	$16,161,000
Equivalent Annual Cost, $/yr	$ 1,717,000	$ 1,797,000	$ 964,000	$ 1,365,000
O & M Costs:				
Anaerobic digestion dry ton/day	119.5	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00	4.00
$/yr	$ 175,000	$ 175,000	$ 175,000	$ 175,000
Sludge pumping - dry ton/day	45.5	45.5	0	45.5
$/dry ton	3.00	3.00	-	3.00
$/yr	$ 50,000	$ 50,000	0	$ 50,000
Dewatering - dry ton/day	119.5	119.5	119.5	119.5
$/dry ton input	20.00	20.00	20.00	25.00
$/yr	$ 872,000	$ 872,000	$ 872,000	$ 1,090,000
Composting - dry ton/day	127.5	63.75	0	0
$/dry ton input	11.00	15.75	-	-
$/yr	$ 512,000	$ 507,000	0	0
Barge & terminal fee				
Compost - dry ton/day	140.3	70.1	0	0
$/dry ton	9.50	9.50	-	-
Filter cake - dry ton/day	0	63.75	127.5	127.5
$/dry ton	-	15.80	17.70	15.80
$/yr	$ 487,000	$ 611,000	$ 824,000	$ 735,000
Compost distribution - dry ton/day	140.3	70.1	0	0
$/dry ton	4.30	4.30	-	-
$/yr	$ 220,000	$ 110,000	0	0
Landfill - dry ton/day	0	63.75	127.5	127.5
truck $/dry ton (30 mi)	-	14.00	14.00	14.00
Landfill fee $/dry ton	-	28.00	28.00	28.00
$/yr	0	$ 977,000	$ 1,955,000	$ 1,055,000
Total Annual Cost, $/yr	$ 4,033,000	$ 4,959,000	$ 4,790,000	$ 5,370,000
Unit cost, $/dry ton*	$ 92.46	$ 113.69	$ 109.82	$ 123.12

*Basis: 119.5 dry tons per day of digested primary sludge solids.

TABLE 8

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 8 LAND APPLICATION AT DISPERSED SITES

	8A	8B	8B*	8C	8D	8D*	8E*
Fixed Costs:							
Capital cost (ENR 2200)	$21,568,000	31,365,000	33,495,000	25,618,000	35,415,000	37,545,000	46,545,000
Equivalent Annual Cost, $/yr	1,970,000	3,782,000	3,972,000	2,264,000	4,075,000	4,265,000	4,917,000
O&M Costs:							
Anaerobic digestion - dry ton/day	119.5	119.5	119.5	119.5	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00	4.00	4.00	4.00	4.0
$/yr	$ 175,000	175,000	175,000	175,000	175,000	175,000	175,000
Sludge pumping							
Deer to Nut - dry ton/day	74	74	74	74	74	74	74
$/dry ton	1.85	1.85	1.85	1.85	1.85	1.85	1.85
$/yr	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Nut to storage-dry ton/day	119.5	119.5	119.5	119.5	119.5	119.5	119.5
$/dry/ton	4.80	4.80	4.80	7.40	7.40	7.40	11.80
$/yr	209,000	209,000	209,000	323,000	323,000	323,000	515,000
Distribution/application -dry ton/day	119.5	119.5	119.5	119.5	119.5	119.5	119.5
$/day ton	20.36	28.32	28.32	20.36	28.32	28.32	28.32
$/yr	888,000	1,235,000	1,235,000	888,000	1,235,000	1,235,000	1,235,000
Pasteurization - dry ton/day	0	0	119.5	0	0	119.5	119.5
$day/ton	-	-	5.60	-	-	5.60	5.60
$/yr	0	0	244,000	0	0	244,000	244,000
Total Annual, $/yr	$ 3,292,000	5,451,000	5,885,000	3,700,000	5,858,000	6,293,000	7,136,000
Unit cost, $/dry ton**	$ 75.47	124.97	134.92	84.83	134.30	144.25	163.60

***Plus disinfection:** See Section 4

****Basis: 119.5 dry tons per day of digested primary sludge solids.**

TABLE 9

SUMMARY OF ANNUAL COSTS

ALTERNATIVE 9 LAND APPLICATION AT MDC OWNED SITE

# DAYS	120	60	120	60
Fixed Costs:	9A	9B	9C	9D
Capital Costs (ENR 2200)	$39,608,000	$41,679,000	$31,341,000	$32,241,000
Equivalent Annual Cost, $/yr	2,954,000	3,152,000	2,674,000	2,841,000
O&M Costs:				
Anaerobic digestion-dry ton/day	119.5	119.5	119.5	119.5
$/dry ton output	4.00	4.00	4.00	4.00
$/yr	175,000	175,000	175,000	175,000
Sludge pumping-dry ton/day	74	74	45.5	45.5
$/dry ton	1.85	1.85	3.00	3.00
$/yr	50,000	50,000	50,000	50,000
Dewatering-dry ton/day	0	0	119.5	119.5
$/dry ton	-	-	20.0	25.0
$/yr	0	0	872,000	1,090,000
Transport to site				
Sludge pumping-dry ton/day	119.5	119.5	0	0
$/dry ton	4.80	4.80	-	-
$/yr	209,000	209,000	0	0
Barge & terminal fees-dry ton/day	0	0	127.5	127.5
$/dry ton	-	-	22.12	22.12
$/yr	0	0	1,029,000	1,029,000
Truck to site-dry ton/day	0	0	127.5	127.5
$/dry ton	-	-	12.38	12.38
$/yr	0	0	576,000	576,000
Storage area-dry ton/day	119.5	119.5	127.5	127.5
$/dry ton	2.71	2.71	10.94	12.61
$/yr	118,000	118,000	509,000	587,000
Application-dry ton/day	119.5	119.5	127.5	127.5
$/dry ton	5.32	5.80	7.13	7.20
$/yr	232,000	253,000	332,000	335,000
Total Gross Annual Cost, $/yr	$3,738,000	$3,957,000	$6,217,000	$6,683,000
Gross Unit Cost, $/dry ton*	85.70	90.72	142.53	153.22
Revenue:				
Corn crop, acres	4380	4380	3130	3130
@ $80/acre net	350,000	350,000	250,000	250,000
Net Annual Cost, $/yr	$3,388,000	$3,607,000	$5,967,000	$6,433,000
Net Unit Cost, $/dry ton*	77.68	82.70	136.80	147.49

*Basis = 119.5 dry tons per day of digested primary sludge solids.

TABLE 10

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 1 INCINERATION - CASE 1A

	Item	Description	Capital Cost ($000)
Nut Island			
1.	Sludge pumping & pipeline*	2-100 gpm 12 in d - 28,000 ft	$ 6,936
Deer Island			
2.	Chemical conditioning & filter presses** incl. building, chemical storage and feed equipment	8-353 ft^3 each	7,660
3.	Incinerators incl. scrubbers - no afterburners	3-22 ft 3 in d x 9H	7,417
4.	Incinerator building	1-13,350 ft^2	2,670
5.	Power generation facilities incl. waste heat boilers, turbine generator, condenser, boiler water treatment & building	1-2000 kw	3,000
6.	Miscellaneous facilities** incl. utilities, tunnels, yardwork & thickener odor control	lump sum	930
7.	Ash disposal incl. barge facilities	lump sum	394
		Total Capital Cost (ENR 2200)	$29,007
		without power facilities	$26,007

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Cost taken from H&E (1973), adjusted to ENR 2200.

TABLE 11

SUMMARY OF CAPITAL COSTS CODES
ALTERNATIVE 1 INCINERATION - CASES 1B, 1C, 1D

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping and pipeline*	2 to 1,000 gpm 12 in d - 28,000 ft	6,936
Deer Island		
2. Chemical conditioning and vacuum filtration**	6 to 750 ft^2 each	7,660
3. Incinerators incl. afterburners and scrubbers	3 to 22 ft 3 in d x 9H	8,054
4. Incinerator building	1 to 13,350 ft^2	2,670
5. Power generation facilities incl. waste heat boilers, turbine generators, condenser, boiler water treatment and building	1 to 2,000 kw	3,000
6. Miscellaneous facilities** incl. utilities, tunnels, yardwork, thickener odor control	lump sum	930
7. Ash disposal barge facilities	lump sum	394
	Total Capital Cost (ENR 2200)	$29,644
	without power facilities	$26,644

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Costs taken from H&E (1975), adjusted to ENR 2200.

TABLE 12

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 2 PYROLYSIS - ALL CASES
INCIN. CASE 1E

Item		Description	Capital Cost ($000)
Nut Island			
1.	Sludge pumping & pipeline*	2-100 gpm 12 in d - 28,000 ft	$ 6,936
Deer Island			
2.	Chemical conditioning & vacuum filters**	6-750 ft^2 ea.	7,660
3.	Pyrolysis furnaces incl. afterburners and scrubbers	3-22 ft 3 in x 9h	8,054
4.	Pyrolysis building	1-13,350 ft^2	2,670
5.	Power generation facilities incl. wasteheat boilers, turbine generator condenser, boiler water treatment & building	1-4000 kw	3,400
6.	Miscellaneous**	lump sum	930
7.	Ash disposal barge facilities	lump sun	394
		Total Capital Cost (ENR 2200)	$30,044
		without power facilities	$26,644

*Costs taken from Stone and Webster (1976), adjusted to ENR 2200.

**Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 13

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 3A COINCINERATION (PUBLIC OWNERSHIP)

Item		Description	Capital Cost ($000)
Nut Island			
1.	Chemical conditioning & vacuum filters	1725 ft^2 Filter area	$ 3,240
2.	Landfill	1 acre	1,000
3.	Barge facilities*	lump sum	241
Deer Island			
4.	Chemical conditioning & vacuum filters	2800 ft^2 Filter area	4,730
5.	Barge facilities*	lump sum	394
South Bay			
6.	Sludge Rotary dryer*	lump sum	2,118
7.	Water-wall incinerator incl. waste heat boilers, electrostatic precipitators, and building (turnkey)	2-850 T/D	38,333
8.	Connection to Boston Edison steam line*	1-2000 ft	388
9.	Site development*	10 acres	265
10.	Misc. facilities**		930
		Total Capital Cost (ENR 2200)	$51,639

*Cost data taken from Stone and Webster (1976), adjusted to ENR Cost Index 2200.

**Cost data taken from H&E (1973), adjusted to ENR Cost Index 2200. Assumed cost distributed between Deer and Nut Islands.

TABLE 14

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 3 COPYROLYSIS 3B

	Item	Description	Capital Cost ($000)
Nut Island			
1.	Chemical conditioning & vacuum filters	1725 ft^2 filter area	3,240
2.	Landfill	1 acre	1,000
3.	Barge facilities	lump sum	241
Deer Island			
4.	Chemical conditioning & vacuum filters	2800 ft^2 filter area	4,730
5.	Barge facilities*	lump sum	394
South Bay			
6.	Solid waste classification and RDF preparation	1-1500 T/D	8,300
7.	RDG conveying, storage (3 day) and feeding	1-900 T/D	4,500
8.	Multiple hearth pyrolysis furnaces incl. wasteheat boilers and electrostatic precipitators	3-25 ft 9 in d x 8h	19,600
9.	Furnace building	1-13,350 ft^2	2,670
10.	Connector to Boston* Edison steam line	1-2000 ft	388
11.	Site development*	10 acres	265
12.	Misc. facilities**		930
		Total Capital Cost (ENR 2200)	$46,258

*Cost data taken from Stone and Webster (1976), adjusted to ENR Cost Index 2200.

TABLE 15

SUMMARY OF CAPITAL COSTS

INDEPENDENT SOLID WASTE INCINERATION - 3C AT SOUTH BAY

Item		Description	Capital Cost* ($000)
South Bay			
1.	Water wall incinerators incl. waste heat boilers, electrostatic precipitators, and building (turnkey)	2-750 T/D	$35,455
2.	Connection to Boston Edison steam line	1-2000 ft	388
3.	Site development	10 acres	265
	Total Capital Cost (ENR 2200)		$36,108

*Cost data taken from Stone and Webster (1976), adjusted to ENR Cost Index 2200.

TABLE 16

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 4 OCEAN DISCHARGE - CASE 4A

	Item	Description	Capital Cost ($000)
Nut Island			
1.	Pasteurization by electron beam irradiation	270,000 gpd @ 400,000 rads	$ 820
2.	Landfill	1/2 acre	500
Deer Island			
3.	Pasteurization by electron beam irradiation	270,000 gpd @ 400,000 rads	820
4.	Misc.	lump sum	930
		Total Capital Cost (ENR 2200)	$3,070

TABLE 17

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 4 OCEAN DISCHARGE -- 4B

Item	Description	Capital Cost
Nut Island		
1. Sludge pumping & pipeline - Nut Is. to Deer Is.*	2-1000 gpm 12 in d - 28,000 ft	$ 6,936
Deer Island		
2. Sludge pumping & outfall	12 in d - 36,000 ft	8,860
3. Misc.	lump sum	930
	Total Capital Cost (ENR 2200)	$16,726

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

TABLE 18

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 4 OCEAN DISCHARGE - CASE 4C

	Item	Description	Capital Cost ($000)
Nut Island			
1.	Sludge pumping & pipeline - Nut Is. to Deer Is.*	2-1000 gpm 12 in d - 28,000 ft	$ 6,936
Deer Island			
2.	Sludge pumping & outfall	12 in d - 36,000 ft	8,860
3.	Pasteurization by electron beam irradiation	540,000 gpd @ 400,000 rads	1,630
4.	Misc.	lump sum	930
		Total Capital Cost (ENR 2200)	$18,356

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

TABLE 19

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 5 OCEAN DUMPING - CASE 5A, 5B

Item	Description	Capital Cost ($000)
Nut Island		
1. Chemical conditioning & vacuum filters	1725 ft^2 Filter area	$ 3,240
2. Landfill	1 acre	1,000
3. Barge facilities	lump sum	241
Deer Island		
4. Chemical conditioning & vacuum filters	2800 ft^2 Filter area	4,730
5. Barge facilities	lump sum	394
6. Miscellaneous facilities* incl. utilities, tunnels, yardwork, and thickner odor control		930
	Total Capital Cost (ENR 2200)	$10,535

*Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 20

SUMMARY OF CAPITAL COST

ALTERNATIVE 5 OCEAN DUMPING - CASE 5C, 5D

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping & pipeline*	2-1000 gpm 12 in d - 28,000 ft	$ 6,936
Deer Island		
2. Chemical conditioning & vacuum filters**	6-750 ft^2 filter area	7,660
3. Barge facilities*	lump sum	635
4. Miscellaneous facilities** incl. utilities, tunnels, yardwork, and thickener odor control	lump sum	930
	Total Capital Cost (ENR 2200)	$16,161

*Costs taken from Stone and Webster (1976), adjusted to ENR 2200.

**Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 21

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 6 COMPOSTING · CASE 6A

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping & pipeline*	2-100 gpm 12 in d - 28,000 ft	$6,936
Deer Island		
2. Chemical conditioning & vacuum filtration**	6-750 ft^2 each	7,660
3. Compost area incl. leachate control	40 acres	1,971
4. Compost equipment	3 - composters 4 - front end loaders 2 - dump trucks 2 - tractors 2 - screens 1 - scale	1,041
5. Barge facilities*	lump sum	635
6. Miscellaneous facilities** incl. utilities, tunnels, yardwork and thickener odor control	lump sum	930
	Total Capital Cost (ENR 2200)	$19,173

*Costs taken from Stone and Webster (1976), adjusted to ENR 2200.

**Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 22

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 6 COMPOSTING - ... CASE 6B

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping & pipeline*	2-100 gpm 12 in d - 28,000 ft	$6,936
Deer Island		
2. Chemical conditioning & vacuum filtration**	6-750 ft^2 each	7,660
3. Compost area incl. leachate control	40 acres	2,960
4. Compost equipment	3 - composters 4 - front end loaders 2 - dump trucks 2 - tractors 2 - screens 1 - scale	1,041
5. Barge facilities*	lump sum	635
6. Miscellaneous facilities** incl. utilities, tunnels, yardwork and thickener odor control	lump sum	930
	Total Capital Cost (ENR 2200)	$20,162

*Costs taken from Stone and Webster (1976), adjusted to ENR 2200.

**Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 23

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 7 LANDFILL - CASE 7A

Item	Description	Capital Cost ($000)
Nut Island		
1. Chemical conditioning & vacuum filtration	1725 ft^2 filter area	$3,240
2. Landfill	1 acre	1,000
3. Barge facilities	lump sum	241
Deer Island		
4. Chemical conditioning & vacuum filtration	2800 ft^2 filter area	4,730
5. Barge facilities	lump sum	394
6. Misc. facilities* incl. utilities, tunnels, yardwork and thickener odor control	lump sum	930
	Total Capital Cost (ENR 2200)	$10,535

*Costs taken from H&E (1973), adjusted to ENR 2200.

TABLE 24

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 7 LANDFILL - CASE 7B

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping & pipeline	2-1000 gpm 12 in d - 28,000 FG	$6,936
Deer Island		
2. Chemical conditioning & vacuum filtration	6-750 ft^2 each	7,660
3. Barge facilities	lump sum	635
4. Misc.	lump sum	930
	Total Capital Cost (ENR 2200)	$16,161

TABLE 25

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 8 - LAND APPLICATION AT PRIVATE DISPERSED SITES - 8A SOUTHERN ROUTE

ONSITE STORAGE 120-DAY APPLY

Item	Description	Capitol Cost
1. Sludge pumping and pipeline - Deer Island to Nut Island	2 to 1,000 gpm 14" ϕ -28,000 ft.	$ 6,936.000
2. Sludge pumping and pipeline to regional transfer sites	12" ϕ to 53 mi.	8,950,000
3. On-site storage lagoon	44 to 2.25 MG	1,936,000
4. Land for lagoons	88 acres	176,000
5. Distribution equipment	20 to 6,000 gal tankers	1,254,000
6. Application equipment	28 to 2,000 gal injector trucks	1,386,000
7. Misc.*	lump sum	930,000
	Total Capital Cost	$21,568,000
	(ENR 2200)	

*Cost taken from Havens and Emerson (1973) adjusted to ENR 2200

TABLE 26

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 8 LAND APPLICATION AT PRIVATE DISPERSED SITES
8B SOUTHERN ROUTE REGIONAL STORAGE 60 DAY APPLY

	Item	Description	Capital Cost ($000)
1.	Sludge pumping & pipeline Deer Is. to Nut Is.*	2-1000 gpm 12 in d - 28,000 ft	$6,936
2.	Sludge pumping & pipeline to regional storage sites	12 in d - 53 mi	8,950
3.	Regional storage lagoons	5 - 20 MG	1,350
4.	Land for lagoons	65 acres	130
5.	Distribution equipment	165 - 6000 gal tankers	10,346
6.	Application equipment	55 - 2000 gal injector trucks	2,723
7.	Miscellaneous facilities** incl. utilities, tunnels, yardwork, thickener odor control	lump sum	930
		Total Capital Cost (ENR 2200)	$31,365

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Cost taken from H&E (1973), adjusted to ENR 2200.

TABLE 27

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 8 LAND APPLICATION AT PRIVATE DISPERSED SITES

8C WESTERN ROUTE ON-SITE STORAGE 120 DAY APPLY

	Item	Description	Capital Cost ($000)
1.	Sludge pumping & pipeline Deer Is. to Nut Is.*	2-1000 gpm 12 in d - 28,000 ft	$6,936
2.	Sludge pumping & pipeline to regional transfer sites	12 in d - 76 mi	13,000
3.	On-site storage lagoon	44 - 2.25 MG	1,936
4.	Land for lagoons	88 acres	176
5.	Distribution equipment	20 - 6000 gal tanker	1,254
6.	Application equipment	28 - 2000 gal injector trucks	1,386
7.	Misc**	lump sum	930
		Total Capital Cost (ENR 2200)	$25,618

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Cost taken from H&E (1973), adjusted to ENR 2200.

TABLE 28

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 8 LAND APPLICATION AT PRIVATE DISPERSED SITES
8D REGIONAL STORAGE 60 DAY APPLY

	Item	Description	Capital Cost ($000)
1.	Sludge pumping & pipeline - Deer Is. to Nut Is.*	2-1000 gpm 12 in. d - 28,000 ft	$6,936
2.	Sludge pumping & pipeline to regional storage sites	12 in. d - 76 mi	13,000
3.	Regional storage lagoons	5 - 20 MG	1,350
4.	Land for lagoons	65 acres	130
5.	Distribution equipment	165 - 6000 gal tankers	10,346
6.	Application equipment	55 - 2000 gal injection trucks	2,723
7.	Miscellaneous facilities** incl. utilities, tunnels, yardwork, thickener odor control	lump sum	930
		Total Capital Cost	$35,415

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Cost taken from H&E (1973), adjusted to ENR 2200.

TABLE 29

SUMMARY OF CAPITAL COSTS

ALTERNATIVE 8 LAND APPLICATION AT PRIVATE DISPERSED SITES
8E REGIONAL STORAGE 60 DAY APPLY

	Item	Description	Capital Cost ($000)
1.	Sludge pumping & pipeline - Deer Is. to Nut Is.*	2-1000 gpm 12 in. d - 28,000 ft	$6,936
2.	Sludge pumping & pipeline to regional storage sites	12 in. d - 129 mi	22,000
3.	Regional storage lagoons	5 - 20 MG	1,350
4.	Land for lagoons	65 acres	130
5.	Distribution equipment	165 - 6000 gal tankers	10,346
6.	Application equipment	55 - 2000 gal injector trucks	2,723
7.	Miscellaneous facilities** incl. utilities, tunnels, yardwork, thickener odor control	lump sum	930
8.	Landfill at Nut Is.	0.5 acre	500
		Total Capital Cost (ENR 2200)	$44,915

*Cost taken from Stone and Webster (1976), adjusted to ENR 2200.

**Cost taken from H&E (1973), adjusted to ENR 2200.

TABLE 30

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 8 LAND APPLICATION
AT MDC OWNED SITE - 9A
(5% Solids 120-Day Apply)

Item	Descriptions	Capital Cost
1. Sludge pumping & pipeline-Deer Is. to Nut Is.	2-1000 gpm 12 in d - 28,000 ft	$ 6,936
2. Sludge pumping and pipeline to storage lagoons	12 in d - 53 mi	$ 8,950
3. Storage lagoons	5-20 MG	$ 1,350
4. Office building & shop	20,000 ft^2	400
5. Land clearing	lump sum	$ 2,300
6. Land purchase	4380 acres + 660 acres buffer	$ 12,600
7. Underground pipeline distribution system	mains, laterals and connections	$ 3,825
8. Pump stations for distribution	lump sum	700
9. Application equipment	7 injector trucks	427
10. Surface runoff collection	lump sum	$ 1,190
11. Misc.		950
	Total Capital Cost (ENR 2200)	$ 39,608

TABLE 31

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 9 LAND APPLICATION
AT MDC OWNED SITE - 9B

(5% Solids 60 Day Apply)

	Item	Descriptions	Capital Cost
1.	Sludge pumping and Pipeline - Deer Is. to Nut Is.	2-1000 gpm 12 in d - 28,000 ft	$ 6,936
2.	Sludge pumping and pipeline to storage lagoons	12 in d - 53 mi	$ 8,950
3.	Storage lagoons	5-20 MG	$ 1,350
4.	Office building & shop	20,000 ft^2	$ 400
5.	Land clearing	lump sum	$ 2,300
6.	Land purchase	**4380 acres + 660 acres buffer**	$ 12,600
7.	Underground pipeline distribution system	mains, laterals and connections	$ 5,469
8.	Pump stations for distribution	lump sum	700
9.	Application equipment	14 injector trucks	854
10.	Surface runoff control	lump sum	$ 1,190
11.	Misc.		950
		Total Capital Cost (ENR 2200)	$ 41,679

TABLE 32

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 8 LAND APPLICATION
AT MDC OWNED SITE - 9C
(25% Solids 120 Day Apply)

Item	Description	Capital Cost
Nut Island		
1. Sludge pumping & pipeline - Nut Is. to Deer Is.	2-1000 gpm 12 in. d - 28,000 ft	$ 6,936
Deer Island		
2. Chemical conditioning and vacuum filtration	6-750 ft^2 each	$ 7,660
3. Barge Facilities	lump sum	635
Application Site		
4. Land clearing	lump sum	$ 1,640
5. Land purchase	3130 acres + 470 acres buffer	$ 9,000
6. Storage shed	7 acres	$ 1,550
7. Office building & shop	20,000 ft^2	400
8. Storage area equipment	10 front end loaders	626
9. Application equipment	22 spreaders	$ 1,114
10. Surface runoff control	lump sum	850
11. Misc.		930
	Total Capital Cost (ENR 2200)	$ 31,341

TABLE 33

SUMMARY OF CAPITAL COSTS
ALTERNATIVE 9 LAND APPLICATION
AT MDC OWNED SITE - 9D
(25% Solids 60 Day Apply)

Item	Description	Capital Cost ($000)
Nut Island		
1. Sludge pumping & pipeline - Nut Is. to Deer Is.	2-1000 gpm 12 in. d - 28,000 ft	$ 6,936
Deer Island		
2. Chemical conditioning and vacuum filtration	6-750 ft^2 each	$ 7,660
3. Barge facilities	lump sum	635
Application Site		
4. Land clearing	lump sum	$ 1,640
5. Land purchase	3130 acres + 470 acres buffer	$ 9,000
6. Storage shed	7 acres	$ 1,550
7. Office building & shop	20,000 ft^2	400
8. Storage area equipment	10 front end loaders	626
9. Application equipment	42 spreaders	$ 2,014
10. Surface runoff control	lump sum	850
11. Misc.		930
	Total Capital Cost	$ 32,241
	(ENR 2200)	

APPENDIX 3-B

METHODOLOGY FOR CALCULATING COST BURDENS

In calculating local cost burdens on households and industries in the MSD, it is necessary to understand the distribution of costs of the overall wastewater systems which include the various sludge alternatives. In addition, a complete assessment requires that ongoing costs of the existing MDC system (i.e., principle and debt service) and of the locally-owned portions of the wastewater treatment system be identified and added to the costs of sludge disposal. The complete costs borne by households and industries can then be assessed in relation to the costs of the sludge disposal alternatives alone. This Appendix will describe the methods used to arrive at the "dollars per household" and "dollars per thousand gallons of industrial flow" that are presented and analyzed in Section 3. The analysis was made as a "snapshot" for expenditures in 1985.

The procedures for calculating these burdens involved the identification of general system and sludge disposal alternative costs, and of costs carried over to 1985 by the existing obligations of the MSD and communities. These costs were then allocated to the three communities selected for detailed study, according to their share of total system flow. The community costs were allocated to households and industries on the basis of assessment shares. Finally, these were aggregated to show total costs for households and industries in each community.

Four types of costs were identified as part of this analysis:

1. General wastewater system costs. These process trains include treatment plants, interceptors and other elements of the MDC wholesale collection and treatment system.
2. Primary sludge disposal options. As described in Section 2 of this report, these are of three basic types: combustion, ocean disposal, and land utilization
3. Continuing costs of the existing MDC system. This group includes principle and debt service payments expected to be made in 1985 on the existing MDC system, and

4. Costs to each community of local collection systems. These costs include expenditures that each of the three communities are expected to make on interceptors and collector sewers in 1980, as well as investments in system rehabilitation.

Costs to households and costs to industries in each of these four groups were determined and aggregated for each of the three communities. The resulting figures (Table 3.8-1) represent costs of the overall system, including sludge disposal and carrying costs to households and industries in each community.

Data Sources

The information required for these calculations came from a variety of sources. Process trains for the general wastewater systems were developed by Kennedy Engineers in their work on Phase II Engineering Portion of the Boston Case Study. Costs for each alternative considered came from those presented in Chapter 10 of their interim report as presented in Table 10-5.*

Costs for the alternative methods of sludge disposal were developed by ERT, as presented in Section 3 of this report. These have been calculated based on the generation of 119.5 dry tons per day of digested primary sludge solids. Both the costs for sludge disposal alternatives and the costs of the general wastewater systems have been calculated using an ENR of 2200.

Local costs for community-owned collector systems in each of the three communities of concern were gathered from EPA's 1976 Needs Survey, as noted in Tables 3-8 and 3-9 of the Kennedy Engineer's Draft Phase II report.** For the purposes of this analysis, costs presented for Facilities Categories III A (I/I correction), III B (Sewer System Rehabilitation), IV A (New Collector Sewers) and IV B (New Interceptors) were used. The Needs survey for these categories used a price level representing January 1976 dollars. For Boston, this is equivalent to an ENR index of 2331. These costs are 1.06 times the costs level used in the EMMA report (which used 1975 dollars);* and local system costs were reduced accordingly.

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*p. 10-89, version dated September 1977.

**p. 3.63-64.

Calculations of payments on bonds issued to finance construction in the existing MDC system were developed from a table published by the Metropolitan Sewerage District which lists Metropolitan Sewerage Loans as of June 30, 1977. This table was included as an attachment to a notice of a public hearing sent to designated officials of member cities and towns of the Metropolitan Sewerage District on September 30, 1977. (See Table 3.8-2.) Expected payments for 1985 were developed from the principle and interest payments listed in this table.

Other sources of data included: population and employment projections, which were developed by the MAPC Water Quality Project, and projections of total flows from each community, which were taken from the EMMA Plan.** Information on sewered populations for each of the three communities also was taken from the EMMA plan.† Residential and industrial assessments were gathered from the Assessor's Office in Boston, Malden and Weston. Additional data on Weston's treatment needs and the costs of alternatives (including joining the MDC system) were taken from the town's draft Step 1 Facilities Plan, prepared by the firm of Camp, Dresser, McKee in 1976.

Case Selection

Table 3.B-2 shows the general wastewater system and sludge disposal alternatives for which the local cost burden analysis was performed.

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*p. 3.59.

**Technical Data, Vol. 2. Table 4-3, pp. 4-11 to 4-13

†Ibid., Table 3-3, pp. 3-8 to 3-10.

TABLE 3.B-1

SUMMARY OF WORKSHEET RESULTS: $/HH/ BOSTON

Sludge Proc. KE Alter	INCINERATION		PYROLYSIS	CO-INCINERATION		OCEAN DISPOSAL	OCEAN DUMPING	COMPOST/LANDFILL		LAND DISPOSAL		LAND/MDC	
	IA	IC	2B	3A	3B	4B	5B	6B	7A	8B	8C	9B	9C
IA	$20.48	$20.76				$18.46		$21.52	$22.11				
IIA	$43.59	$43.87	$44.10	$43.45	$44.17	$41.57	$42.90	$44.69	$45.22	$43.31	$42.90	$41.99	$44.87
IIB	$55.45	$55.73											
IIC	$74.89	$75.17											
IIIA	$38.99	$39.27											
IIIJ	$33.38	$33.66				$31.36	$32.69	$34.42	$35.01				
IIIK	$30.00	$30.28				$27.98	$29.31	$31.04	$31.63				

SUMMARY OF WORKSHEET RESULTS: $/000 GAL. INDUSTRIAL FLOW

IA	$ 0.2664	$0.2711				$0.2350		$0.2747	$0.2772				
IIA	$ 0.8690	$0.8727	$ 0.8758	$ 0.8601	$ 0.8665	$ 0.8376	$0.8509	$ 0.8773	$ 0.8798	$ 0.8659	$0.8586	$0.8558	$0.8862
IIB	$ 0.9949	$0.9986											
IIC	$ 0.8661	$0.5959											
IIIA	$ 0.8123	$0.8160											
IIIJ	$ 0.6732	$0.6769				$0.6418	$0.6551	$0.6815	$0.6841				
IIIK	$0.5614	$0.5651				$0.5301	$0.5434	$0.5698	$0.5723				

SUMMARY OF WORKSHEET RESULTS: $/HH/ MALDEN

Sludge Alter. / KE Alter	INCINERATION		PYROLYSIS	CO-INCINERATION		OCEAN DISPOSAL	OCEAN DUMPING	COMPOST	LANDFILL	LAND DISPOSAL		LAND/MDC	
	IA	IC	2B	3A	3B	4B	5B	6B	7A	8B	8C	9B	9C
IA	$19.33	$19.61				$17.46		$20.32	$20.89				
IIA	$41.05	$41.31	$41.53	$40.91	$41.59	$39.16	$40.41	$42.02	$42.59	$40.79	$40.40	$39.54	$42.25
IIB	$52.19	$52.45											
IIC	$70.40	$70.66											
IIIA	$36.71	$36.97											
IIIJ	$31.47	$31.73				$29.58	$60.00	$32.44	$33.01				
IIIK	$28.30	$28.56				$26.41	$27.66	$29.27	$29.84				

SUMMARY OF WORKSHEET RESULTS: $/000 GAL. INDUSTRIAL FLOW

IA	$0.2975	$0.3016				$0.2662		$0.3060	$0.3038				
IIA	$0.8934	$0.8975	$0.9005	$0.8844	$0.8911	$0.8621	$0.8752	$0.9019	$0.9042	$0.8904	$0.8830	$0.8803	$0.9107
IIB	$1.0193	$1.0309											
IIC	$0.8768	$0.8947											
IIIA	$0.8367	$0.8408											
IIIJ	$0.6976	$0.7018				$0.6663	$0.6795	$0.7061	$0.7084				
IIIK	$0.5854	$0.5900				$0.5546	$0.5677	$0.5944	$0.5967				

SUMMARY OF WORKSHEET RESULTS: $/BBl/WESTON (MDC ALTERNATIVE)

Sludge Alter.	INCINERATION		PYROLYSIS	CO-INCINERATION		OCEAN DISPOSAL	OCEAN DUMPING	COMPOST	LANDFILL	LAND DISPOSAL		LAND/MDC	
KE Alter.	IA	IC	2B	3A	3B	4B	5B	6B	7A	8B	8C	9B	9C
IA	$2.41	$2.45				$2.32		$2.46	$2.58				
IIA	$3.81	$3.85	$3.84	$3.79	$3.85	$3.72	$3.78	$3.86	$3.98	$3.82	$3.78	$3.75	$3.86
IIB	$4.36	$4.40											
IIC	$6.90	$6.94											
IIIA	$3.64	$3.68											
IIIJ	$3.29	$3.33				$3.20	$3.26	$3.34	$3.46				
IIIK	$3.05	$3.09				$2.96	$3.02	$3.10	$3.22				

SUMMARY OF WORKSHEET RESULTS: $/000 GAL. INDUSTRIAL FLOW

IA	$0.2067	$0.2067				$0.1768		$0.2175	$0.2180				
IIA	$0.0758	$0.0758	$0.7636	$0.7529	$0.7529	$0.7283	$0.7416	$0.7689	$0.7695	$0.7529	$0.7529	$0.7449	$0.7743
IIB	$0.8867	$0.8867											
IIC	$0.5869	$0.5869											
IIIA	$0.7047	$0.7047											
IIIJ	$0.5762	$0.5762				$0.5462	$0.5596	$0.5869	$0.5874				
IIIK	$0.5244	$0.5244				$0.4944	$0.5078	$0.5351	$0.5356				

Seven general wastewater system cases were chosen out of the sixteen developed by Kennedy Engineers. These seven cases represent the recommended EMMA alternatives, and four other cases which are most appropriate for generating primary sludge. Briefly, these cases are:

- IA, which would include the rehabilitation and upgrading of the present facilities provided by the MDC system, with only moderate increases in population.
- IIA, the recommended EMMA Plan, representing an expanded service area that would include most of the communities tributary to Boston Harbor. A total of 32 projects are grouped into five overall categories, which include expansion and rehabilitation of the Deer Island and Nut Island plants, construction of the Middle Charles River and the Upper Neponset River satellite plants, relief and extension interceptors, pump stations, and combined sewer overflow projects, including sludge management for secondary and AWT sludges.
- IIB, which is substantially the same as Alternative IIA, with additional modifications and rehabilitation proposed at the Deer and Nut Island Treatment Plants. The service area and level of service, population served, influent and effluent strength are the same here as in Alternative IIA.
- IIC, which again is substantially the same as Alternative IIA, with modifications to the grant eligibility formulas used in preparation of the costs, based on Section h(2) of Appendix A of 40 CFR 35 -- Grants for Construction of Treatment Works -- Cost-Effectiveness Analysis Guidelines, as proposed to be amended in the February 4, 1977 notice in the Federal Register. By determining grant eligibility on a ratio-of-flows approach, the amount eligible for

TABLE 3.B-2

SUMMARY OF WORKSHEET RESULTS

	KE Alternative # (with primary sludge removed)						
	IA	IIA	IIB	IIC	IIIA	IIIJ	IIIK
Annual Capital	$5.07M	$36.06M	$33.90M	$36.06M	$36.26M	$29.30M	$22.44M
Annual DS	4.51M	32.02M	30.09M	32.02M	32.20M	26.02M	19.92M
Annual O&M	8.35M	24.05M	35.95M	24.05M	19.55M	15.65M	13.85M
BOSTON							
HH Total Cost	1977.9K	6644.2K	9039.4K	12964.0K	5715.8K	4583.8K	3900.8K
$/HH	$ 9.80	$32.91	$44.77	$64.21	$28.31	$22.70	$19.32
Ind. Total Cost	751.9K	3362.9K	3908.5K	3350.5K	3117.2K	2514.6K	2030.3K
$/gal Ind	$ 0.0633	$ 0.2833	$ 0.3212	$ 0.2822	$ 0.2626	$ 0.2118	$ 0.1710
MALDEN							
HH Total Cost	170.5K	573.6K	780.5K	1118.8K	493.0K	395.7K	336.7K
$/HH	$9.18	$30.88	$42.02	$60.23	$26.54	$21.30	$18.13
Ind Total Cost	75.7K	340.0K	394.5K	349.2K	315.8K	254.4K	205.3K
$/gal Ind	$0.0636	$ 0.2856	$ 0.3314	$ 0.2933	$ 0.2653	$ 0.2137	$ 0.1724
WESTON (MDC)							
HH Total Cost	1.8K	6.6K	8.5K	17.2K	6.0K	4.8K	4.0K
$/HH	$0.52	$1.92	$2.47	$5.01	$1.75	$1.40	$1.16
Ind Total Cost	3.0K	13.3K	15.7K	10.1K	12.3K	9.9K	8.0K
$/gal Ind	$0.0586	$0.2599	$0.3068	$0.1974	$0.2404	$0.1935	$0.1563

TABLE 3.B-3

CASE SELECTION

SLUDGE ALTERN. \ KE ALTERN.		EXISTING SITUATION				EMMA ALTERNATIVES			KENNEDY ENGINEERS ALTERNATIVES											
		IA	IB	IC	ID	IIA	IIB	IIC	IIIA	IIIB	IIIC	IIID	IIIE	IIIF	IIIG	IIIH	IIIJ	IIIK
INCINERATION	1A	●				●	●	●	●									
	1B																●	●
	1C	●				●	●	●	●									
	1D																●	●
PYROLYSIS	2A																	
	2B					●												
	2C																	
CO-INCINERATION	3A					●												
	3B					●												
OCEAN DISPOSAL	4A																	
	4B	●				●	●											
OCEAN DUMPING	5A																●	●
	5B					●	●											
	5C																●	●
	5D																	
COMPOSTING	6A																	
	6B	●				●	●											
LANDFILL	7A	●				●	●										●	●
	7B																●	●
LAND DISPOSAL	8A																	
	8B					●												
	8C					●												
	8D																	
	8E																	
LAND/MDC	9A																	
	9B					●												
	9C					●												
	9D																	

federal grants would be considerably less than that calculated in the EMMA Plan.

- IIIA, which involves the replacement of the existing Nut Island Treatment Plant with a single plant with more capacity. Services areas would remain as proposed in EMMA, and the satellite treatment plants proposed under the EMMA Recommended Plan would not be built.

- IIIJ, where the Deer and Nut Islands Treatment Plants would provide only primary treatment, with the service areas and all other facilities remaining the same as those proposed under Alternative IIIA. An ocean discharge (in deep water beyond The Graves) would eliminate the need for secondary treatment and secondary sludge disposal. This process is referred to as marine secondary treatment.

- IIIK, which is the same as Alternative IIIJ with the exception that present Harbor discharge points would be retained, rather than constructing deep ocean outfall. The service areas and levels of service are the same as under Alternative IIIJ.

With the exception of the EMMA recommended Plan alternatives, the cases selected for this analysis were chosen on the basis of their applicability to primary sludge generation. The case in group I is basically that of the "no-build" option, for which the primary sludge disposal system under consideration in the on-going EIS has been designed. The cases selected in group III would be generating the largest amounts of primary sludge, and thus the most interesting for this study. All cases under the EMMA Recommended Plan (group II) were selected, due to their relative likelihood of implementation.

A number of sludge disposal cases were also chosen for the analysis, including

- incineration cases 1A and 1C
- pyrolysis case 2B
- co-combustion cases 3A and 3B
- ocean disposal case 4B (long outfall)
- ocean dumping case 5B
- composting case 6B
- landfill case 7A
- land application cases 8B, 8C, 9B, and 9C

These cases were chosen as representative of each sludge management alternative. It was also assumed that limited construction options, such as Kennedy Engineers alternatives I, IIIJ, and IIIK, would only consider a limited range of sludge alternatives. That is, a system committed to primary treatment only with ocean outfall might consider the ocean options, landfilling, and perhaps the main incineration option, but would be less likely to choose options which are currently more speculative, like land application and pyrolysis. This is the justification for the matrix shown in figure 3.B-3.

Calculating Local Burdens

Translating the alternatives described above into costs to households and industries in Boston, Malden and Weston was accomplished in a series of six steps. First, the costs for disposing of primary sludge were separated from each of the general wastewater system alternatives selected for study. The annual payments toward each system for the year 1985 were calculated for each alternative. Then, the annual local costs of the general wastewater systems and the annual costs of each sludge disposal alternative were allocated to each of the three communities. Next, annual payments that each community could expect in 1985 on the existing MDC system loans were calculated. Similarly, annual payments that each community could expect to make in 1985 on Category III and IV expenditures as defined in EPA's 1976 Needs Survey were determined. Finally, the costs in each of these steps for households in each of the three communities were estimated, as were the costs per thousand gallons of industrial flow.* The resulting costs were expressed in terms of dollars per household and dollars per thousand gallons of industrial flow in each community, and represent total expected expenditures that each group could expect to make for wastewater treatment in 1980.

A. Separation of Primary Sludge Costs from the General Wastewater Treatment System Alternatives

In determining costs of each alternative wastewater treatment option, Kennedy Engineers assumed that the primary sludge disposal method would be the incinerator designed by Havens and Emerson, for which EPA is now preparing an EIS. This incinerator was assumed to have the following costs associated with it:

- Capital Cost: $25.573 million
- Annual Operations and Maintenance Costs: $1.55 million
- Present Worth: $30.3 million

Construction is assumed to start in June, 1979, with the incinerator completed in April, 1980.

Other assumptions made in calculating the costs of the general wastewater systems were that the midpoint in construction of the nonsludge portions of the systems would occur in January 1982 for all alternatives; and that this construction would be complete in January 1984, whereupon annual payments toward operations and maintenance of the non-sludge portions of the system would begin. Finally, all present worth calculations were made in January, 1975 dollars.

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*Including ICR contributions.

The costs of the primary sludge incinerator were separated from the costs of each general wastewater system in the following way:

1. Annual O&M costs for sludge handling were subtracted from the annual O&M costs for each general system.
2. The present worth of the total capital and O&M costs for sludge handling were subtracted from the present worth of these costs for each general system. The present worth of the non-sludge O&M costs was then determined, using the annual non-sludge O&M payments calculated in Step 1, an interest rate of 7%, a 20-year payback period for the system as a whole, and subtracting the present worth of the first nine years when the system would be under construction and no O&M payments would be made. The present worth of the non-sludge capital was determined by subtracting the present worth of the non-sludge O&M payments from the total present worth of the capital and O&M costs for each general system.
3. The present worth of the capital was inflated to January 1982 levels using an interest rate of 7%.
4. A total annual payment was then calculated for each general system alternative, using an interest rate of 7% and a payback period of 20 years.
5. Debt service for these payments was calculated, again using a payback period of 20 years.
6. The annual payment toward principle was calculated from the total annual payment for each general system.
7. The total debt service payments calculated in Step 5 were broken down into annual payments.

These calculations produced separate annual costs for 1985 for the non-sludge portions of each general wastewater system alternative for principle, debt service and O&M.

B. Allocation of General Wastewater System and Sludge Handling Costs to Communities

The costs of each general system alternative and sludge handling option were allocated to each of the three communities in the same manner. Separate worksheets were prepared for the allocation of general system costs and for the allocation of sludge disposal costs. The methodology for allocating these costs was:

1. Local shares of the capital costs were determined by multiplying the total capital costs of each alternative by each community's share of flow in the MDC system. Each community's share was then multiplied by a factor of 0.1 to reflect 100% grant eligibility of the capital costs of each alternative. This produced local capital costs for each community.
2. The same procedure was followed to determine both local debt service payments and local shares of the O&M costs.
3. Finally, figures for industrial cost recovery payments in each community were developed by multiplying the total capital costs for an alternative by a factor of 0.9 (to reflect grant eligibility). The result was then multiplied by each community's share of capital payments that will be necessary to meet ICR requirements.

C. Allocation of Community Shares to Households

The allocation of community shares of the costs of the general wastewater systems and of each sludge disposal alternative was also done in much the same way:

1. Costs for O&M for each alternative were multiplied by the proportion of residential flow in each community (which was derived by subtracting the community's industrial flow from its total contribution to the MDC system). This produced O&M costs that could be attributed to households.
2. Capital costs to be borne by households were determined by adding the community's total capital costs to its debt service payment and multiplying this subtotal by the residential flow in each town.
3. Total household costs were obtained by adding the capital costs borne by households to the O&M costs borne by households.
4. These total household costs were then divided by the number of households served by the MDC system in Boston and Malden to arrive at costs per household. (In both of these communities, almost 100% of the population is served by the system.) In Weston, the total number of households in the town was also used, as most of the area that is projected to be sewered (in the Weston Facilities Plan) under the MDC alternative is occupied by municipal structures, with a few businesses and even fewer households contributing. It was felt that with so much of the flow contributed by town buildings the costs would be borne by the whole town, through the property tax.

D. Allocation of Community Shares to Industries

The allocation of community costs to industries in each community was done in a similar manner to the household allocations. Again, the methodology was the same for allocating costs of the general wastewater systems and for the sludge disposal alternatives:

1. Household O&M was subtracted from community O&M costs to obtain the total industrial O&M burden.
2. The capital payment and debt service borne by households was subtracted from the community's total capital and debt service payments, to obtain industrial capital costs.
3. Total costs allocated to industries were obtained by adding ICR payments and the industrial share of the community's O&M payments to the industrial capital costs.
4. These totals were then divided by industrial flows in each community to obtain costs per thousand gallons of industrial flow.

E. Calculation of 1985 Payments on Existing MDC System

The total bonded indebtedness of the MDC system on which payments will be made in 1985 was identified from the table entitled "Metropolitan Sewerage Loans" attached to a memorandum sent to designated officials of member cities and towns of the Metropolitan Sewerage District, dated September 30, 1977. Only those bonds on which payments will remain to be made in 1985 were used in this analysis, and it was assumed that the entire authorized amount of each would be sold by that year. Bonds for which no sales have been made were not included in the calculations, as it was not possible to determine what proportion would be sold by 1985. It was assumed that principle payments would be the same in each year, although the annual interest payment will change as the unpaid principle decreases. The annual principle and interest payments were determined for each outstanding bond, and aggregated to obtain total for total annual payments in 1985. These were then allocated to each community based on their share of the total system flow, just as the costs for the general wastewater systems and each sludge disposal alternative were allocated. Within each community these costs were apportioned to households and industries in the same manner as that described in C. and D. above.

F. Calculation of Costs of Local Systems Expected in 1985

Expected local expenditures were obtained from EPA's 1976 Needs Survey for each of the three communities of interest. Needs identified in Categories III and IV (System rehabilitation, interceptors and collector sewers) were broken out and added to obtain a total for expected local expenditures. It was assumed that these expenditures would be entirely grant eligible, so that the local share of the capital costs would amount to 10% of the total. It was also assumed that the payments on these expenditures would be spread over a twenty-five year period, so that the annual cost was calculated by dividing the payback period into the local share of the expenditure for each of the three communities. Annual payments in 1985 were then determined from the annual cost figures, using a 7% interest rate and the twenty-five year payback period. It was assumed that the projects would start in 1980, so that payments in 1985 would represent the fifth year of the payback period. Within each community, costs were allocated to households and industries based on their respective proportions of the community's total assessment, in the same manner that the costs of the general wastewater systems and the sludge disposal alternatives were allocated to each category of user.

G. Aggregation of Costs

The final step was to sum the costs to households and to industries in each community, providing the totals shown above in Table 3.B-1.

APPENDIX 3-C

TRANSPORTATION-TRAINS FOR ALTERNATIVES

The ER&T team contemplated nine methods of sludge disposal, namely; incineration; pyrolysis, co-incineration, ocean discharge, ocean dumping, composting, landfilling and two types of land application for agricultural purposes.

The incineration alternative had five optional methods of ash production. The ash transportation method was common to all five options and consisted of barge transportation of ash in container-trailers to Mystic Terminal and then trucking to the Plainville landfill site.

The three optional methods of ash production under the pyrolysis alternative had a common ash transportation method, the same as described for the incineration alternative.

The co-incineration alternative has also three optional methods of ash production. All three options contemplated transportation of dewatered sludge in container-trailers to Wiggins Terminal and then trucking to the City of Boston solid waste incinerator. The resulting ash would then be loaded into the trailers and trucked to the Plainville landfill site.

The ocean-discharge alternative contemplated no additional transportation mode in its 4A option. The options 4B and 4C* proposed to utilize a 36,000 foot-long ocean outfall pipeline.

The ocean-dumping alternative considered two options of sludge production and basically one method of transportation, namely: barging to sea for dumping. The cost variation was based on selection of the dumping areas. One option considered a 30 mile hauling distance, the other a 70 mile distance.

The composting-landfilling alternative considered four optional methods of sludge disposal. Two of the options included disposal of composted sludge and two others the disposal of dewatered sludge in the landfill. All the options had a common sludge transport-train, namely: barging of either composted or dewatered sludge in container-trailers to Mystic and then trucking to the regional "give-away" sites or to the Plainville landfill site.

The land application alternative considered a total of eleven options. Basically, however, it contemplated disposal of sludge in a liquid form and a dewatered form. The liquid sludge option utilized either dispensed sites or MDC owned sites for disposal. The transport mode used for this option was pipeline transport to dispersed storages. The costs of sludge transportation from dispersed storages to either privately owned farms or MDC owned land was included with land application costs. The dewatered sludge option utilized MDC owned sites only. The transport mode used for this option was barge transport of sludge in container-trailers from Deer Island to Sandwich Slip, located on Cape Cod, and then trucking to the regional sites for storage and application. The cost of transportation from storage to fields was included with the cost of sludge application to land.

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*Discussed in Section 4.

The ER&T team also identified all four modes of transportation. It selected only three for cost comparison. These were: pipeline, barging and trucking. The rail transport mode and its rejection relative to other modes and their costs will be discussed in the chapters on cost and cost sensitivity.

Local Transportation Costs

Although it is not possible to extract the component making-up all the transportation costs in the Havens and Emerson or the EIS reports, an attempt will be made here to compare these components which are extractable with the cost components used in this study. This comparison will show the agreements as well as differences among the different costs and will attempt to analyze the reasons for divergence or convenience of some of these costs. This comparison will be organized on the basis of the individual transportation modes but may have to cross these lines to bring to the attention of the reader some overall transport economies or the lack of them.

Truck Transportation

Havens and Emerson utilized a short haul truck transport only in the incineration alternative. This alternative became later a recommended mode of operation and therefore trucking became a recommended mode of transport. Trucks and trailers would be purchased and amortized over a 10 year period, with a capital recovery factor of 5%. The cost of a truck-trailer unit was listed as $35,000 in 1973 or in 1975 prices as $41,000. The maintenance cost in 1975 prices was shown as $2300 per year unit or $1.12 per hour. The operating cost in 1975 prices was $0.29 per mile and the labor cost was $6.61.

The EIS Report utilized truck transport for short hauls of 30 miles for ash disposal in landfill and long hauls of 50-70 miles for land application alternatives. The truck transport mode of haulage of relatively large volumes of sludge over long distances resulted in large expenditure of capital for the equipment and large annual expenditures for labor, fuel and maintenance.

The EIS costs, the base costs for comparisons in 1975 dollars, listed the following expenditures:

Truck and trailer = $35,000 + $22,000 = $55,000 each, purchased and amortized over the 10 year period.

The mileage cost of $0.10 per mile reflected the cost of maintenance and other minor costs associated with vehicle operation. Fuel costs were $0.38 per gallon of diesel fuel, and the labor costs were $6.84 per hour. The capital recovery factor was 6.125%.

The ER&T Team utilized the truck transport in the incineration, pyrolysis, co-incineration, composting and land application alternatives. The haul distance did not exceed 30 miles.

The ER&T Team independently checked the cost of trucks and trailers and their expected life with the manufacturers and arrived at the following expenditures:

Truck and trailer in 1975 prices = $32,000 + $13,000 = $45,000 each purchased and amortized over 7 year period at the capital recovery factor of 7%. The maintenance and operating cost was posted at $3.00 per hour of operating and the labor cost at $7.00 per hour.

Analyzing the cost factors arrived at by the three reports, one can see that the capital costs used by Havens and Emerson bracketed the ER&T cost on the low side and the EIS cost bracketed it on the high side. Based on this bracketing and the independent check by ER&T team one may consider the ER&T prices as representative costs for the required equipment. The labor costs utilized by the three reports are close enough to assume no significant overall differential for labor expenditures. The operation and maintenance costs vary appreciably and based on a one-way haul of 30 miles and travel time of 30 mph can be shown to be for a round trip as follows:

Havens and Emerson:

Maintenance: @ \$1.12/hr. = 2x 1.12 = 2.24
Operating Cost: @ 0.29/mi = 60x 0.29 = 17.40
Labor @ 6.84/hr. = 2x 6.61 = 13.22
Total = \$32.86/round trip
or \$ 0.55/mile

EIS:

Maintenance: @ \$0.10/mi = 60x 0.10 = 6.00
Fuel @ 0.38/gal @ 6 mi/gal (assumed) = 60/6 x 0.38 = 3.80
Labor @ 6.61/hr. = 13.68
Total = \$23.48/round trip
or \$ 0.39/mile

ER&T:

Operation & Maintenance @ \$3.00/hr. = 2 x 3.00 = 6.00
Labor @ \$7.00/hr. = 2 x 7.00 = 14.00
\$20.00/round trip
or \$ 0.33/mile

The ER&T Team utilized truck transport to haul 95% solids ash, 50% solids composted sludge and 25% dewatered sludge and arrived at the following cost ranges in dollars per dry ton:

Ash to landfill, 30 mile one-way trip	\$ 6.48/D.T.
Composted Sludge, 4-28 mile one-way trip	\$ 2.23-4.25/D.T.
Dewatered Sludge, 4-28 mile one-way trip	\$ 7.30-12.20/D.T.
Dewatered Sludge, 5-20 mile one-way trip	\$12.32/D.T.

Barge Transportation

Havens and Emerson considered but not not utilize the barging mode of sludge transport in its alternatives. However, the following costs can be recovered from this report:

1500 ton barge, 1975 cost = $580,000 amortized over 20 year period and capital recovery factor of 5%. The annual maintenance cost, 1975 prices = $8900. The towing charge of $0.00348 per wet ton mile and labor cost of $6.61 per hour were also shown.

The EIS utilized the barging mode for ash transport to Mystic and to sea for disposal. Dewatered sludge was also barged to Mystic and to sea. The following costs can be recovered from the report:

400 ton barge, 1975 cost = $395,000

1500 ton barge, 1975 cost = $1,000,000

Amortization period is assumed at 20 years and a capital recovery factor of 6.125%. Barge maintenance cost could not be identified in the EIS report. The towing charge of $0.003 per ton mile and labor cost of $6.84/hr. was also used.

The ER&T Team utilized barge transportation as sole transport mode or as part of the transport-train in the following alternatives: incineration, pyrolysis, co-incineration, ocean dumping, composting-landfilling and land application.

The following capital costs were obtained from EPA publication "The Barged Ocean Disposal of Wastes," 1971 and from telephone conversations with a barge manufacturer.

	Publication	Phone Conversation
400 ton barge	$ 92,000	$300,000
1000 ton barge	231,000	356,000
1500 ton barge	347,000	--
2000 ton barge	462,000	508,000
3000 ton barge	697,000	660,000

The publication contemplated 10 year life of the primary barge and 20 year life of the standby barge, both amortized at 8%. The barge manufacturer's suggestion was for 20 year life of the barge which was then amortized at 7%. The barge maintenance costs were posted at 12%

of the annual capital costs. The towing costs were computed from the following formula:

$$C_t = T_c \left(\frac{X}{V} + t\right)$$

where C_t = total towing cost in dollars/trip

T_c = towing charge, \$109/hr.

X = round trip distance traveled in miles

V = tug speed, assumed 6 miles/hr.

t = unloading time, hrs.

The labor cost of \$7.00/hr. is included in the towing charge formula shown above. The towing charge of \$109/hr. was checked against fees presently charged by barging companies in the Boston area. This fee presently stands at \$195/hr. or in 1975 dollars at \$165/hr. However, this cost was quoted for a sporadic towing and apparently can be negotiated when an offer of long-term contract is presented to the barging company officials.

In order to compare the barging costs as enumerated above the following calculations were performed: Assume ocean option of sludge disposal and the disposal site 70 miles east of Boston area.

Havens and Emerson, 22% dewatered sludge

Total wet tonnage = 128 D.T./day x 365x $\frac{100}{22}$ =	213,000 wet tons
1500 barge annual cost = 580,000 x 0.8024 =	46,500
Towing 0.00348 x 213,000 x 140 =	103,800
Maintenance	8,900
	159,200

$$\text{Cost per dry ton} = \frac{159{,}200}{213{,}000} \times \frac{100}{22} = 3.40/\text{D.T.}$$

EIS, 22% dewatered sludge, 213,000 wet tons/yr.

1500 barge annual cost = 100,000 x 0.08807 = 88,000
Towing 0.003 x 213,000 x 140 = 89,500
Labor = 136,100
313,600

Cost per dry ton = $\frac{313,600}{213,000} \times \frac{100}{22}$ = \$6.69/D.T.

ER&T report, 25% dewatered sludge, 187,000 wet tons/yr.

Using 3000 ton barge as calculated for this option of transport the cost was \$7.02/D.T.

Using 1500 ton barge for comparison the per dry ton cost was computed as follows: no. of trips = 187,000/1500 = 125 trips.

Barge fixed costs = 97,400
Towing fee = 109 $\left(\frac{140}{6} + 4\right)$ x 125 trips = 372,500
Total = 469,900

Cost per dry ton = $\frac{469,900}{187,000} \times \frac{100}{25}$ = \$10.05/D.T.

The differential in cost between H & E and EIS reports is due to lack of labor cost in the H & E computation and the differential in capital costs of barges. The differential in cost between H & E and EIS on the one hand and this report on the other is probably due to barge cost differential and the fact that this report utilized a standby barge. Most of the cost differential is in the towing fee which was calculated for this report as follows:

Cost per ton mile = $\frac{372,500}{187,000 \times 140}$ = 0.0142 per ton mile. This fee is almost five times as much as the fees charged by H & E and in the EIS but it is comparable to recent fees charged by towing companies as shown previously.

In considering different barging options the following costs in dollars per dry ton were computed:

25% sludge	
Ocean disposal 30 miles	$ 5.05
Ocean disposal 70 miles	$ 7.02
Deer-Nut Mustic 21.5 miles	$ 7.74
Deer-Mystic 6.5 miles	$ 6.62
Nut-Mystic 10 miles	$ 9.74
Deer-Sandwich 50 miles	$12.16
50% sludge	
Deer-Mystic 6.5 miles	$ 4.56
95% ash	
Deer-Mystic 6.5 miles	$ 3.48

Rail Transportation

Rail transportation cost comparisons will be attempted only between the Havens and Emerson Report and the ER&T Team costs due to the fact that the EIS did not utilize the rail transport option.

Havens and Emerson utilized rail mode to transport 22% dewatered cake and wet oxidized sludge to remote land sites for application. The cost of railroad cars was posted at $40,800 in 1975 dollars with a 20 year life and a 5% capital recovery factor. The transportation charge was $1200 per day and the labor cost $6.61/hr. The rail cars were to be purchased and the locomotive leased. It is assumed here that the per day cost of $1200 included the cost of the locomotive, trackage fees, switching fees, fuel and the labor cost of the train crew. It is not possible to extract the annual maintenance fee from the H & E report and therefore the assumption will be made here that the capital cost $7,720,000 (1973 dollars) includes all the necessary facilities and the rolling stock and will be amortized for 20 years at 5% in 1975 dollars.

$$\text{Annual cost} = 7{,}720{,}000 \times \frac{2200}{1896} \times 0.08024 = \$719{,}000/\text{yr.}$$

Assuming also that unit train will be used on a daily basis the total operating cost is computed as:

Operation = \$1220 x 365 = \$445,300 yr.

Total tonnage carried is 213,000 tons per year at 22% solids. Therefore the cost per dry ton per year is computed as:

Total cost = 719,000 + 445,300 - 1,164,300/213,000 = \$547/wet ton or $5.47/x \frac{100}{22} = 24.85$/D.T.

This report did not utilize the train transport mode in the final analysis of transportation costs. However, the costing of alternate rail transport mode for liquid sludge and 25% dewatered sludge was performed. This analysis showed that it is considerably cheaper to transport the 25% dewatered sludge to MDC owned sites southeast of Boston via a barge and containerized truck transport than via a train and containerized truck. The cost differential appears to be \$3.26 per dry ton. On the other hand transportation of 5% liquid sludge to remote sites showed in some cases only slight differential between the pipeline transport and the unit train tank car transport modes. The costs arrived at are in dollars per ton and are as follows:

Land Location	Pipeline Mode	Train Mode
MDC sites s-e Boston	19.60	23.74
5 Dispersed Sites	?	?
2 s-e Boston	19.60	30.85
3 western	28.80	35.94
3 Dispersed western sites only	28.80	29.99

The bulk transport of 25% sludge in hopper cars was also considered but its economics were rejected on the basis of the additional materials handling requirement at the loading-unloading stations and the time element differential for loading-unloading containerized trailers versus the bulk loading and unloading with clam shell buckets.

Rail transport computations in this study were based on the following 1975 costs amortized in 10 years at 7%.

Flat cars: $38,000
Tank cars: $30,000
Flat car locomotive: $400,000
Tank car locomotive: $473,000
Train crew at $7.00/hr.: Engineer, 2 Breakmen, Conductor
Train trackage fee: $5.00 per train mile
Switching fee: 25% sludge assumed $0.25/ton
5% sludge assumed $0.10/ton.

Fuel costs @ $0.32/gal and 6 gal/mile running, 8 gal/hour waiting
locomotive maintenance @ $0.34/mile travelled
Car maintenance @ 2% annual.

In addition, to arrive at the total rail transport cost the following capital and annual costs were included:

Switching yards; including land, track costs, switches and signals.
unloading trenches and unloading costs.
1.0 million gallon covered storage tank.
Pumping stations and pipelines.

Pipeline Transportation

Pipeline transportation modes were utilized by Havens and Emerson as a long haul option to land application sites and as a short haul option to transport sludge from plants to mainland filtration facility for dewatering. The EIS did not utilize pipelines as possible transportation options. The ER&T Team utilized pipeline mode in the same fashion as the Havens and Emerson Report. For this reason the cost comparison will be attempted between the Havens and Emerson reports.

The Havens and Emerson pipeline costs were based on the following assumptions:

Useful life = 40 years @ 5% capital recovery.
Pipeline maintenance = 1% per year of the capital cost.
Power cost = $0.0174 per KWH
Booster stations spaced at intervals equivalent to TDH = 250 ft.

Since the annual operating cost of a pipeline system could not be extracted from the Havens and Emerson report only the capital costs will be compared with the similar ER&T costs. The 1975 capital cost of the pipeline system for land application alternative considered by Havens and Emerson is $18,693,000.

For this study, the pipeline design was based on the following assumptions:

Useful life = 50 years @ 7% capital recovery.
Pipeline maintenance = 2% per year of the capital cost.
Power cost = $0.0275 per KWH
Booster stations = ~150 HP units.
Pipeline construction cost = $25.44/ft installed
Total length of pipeline = 129 miles.

The capital cost of the pipeline considered by ER&T Team for the land application alternative using dispersed site option is $21,950,000.

Since generally the land sites considerd by Havens and Emerson and ER&T are identically located it is assumed here that Havens and Emerson pipeline mileage is the same as ER&T mileage. The differential in price between Havens and Emerson and ER&T is some 17.5% and can be attributed to different unit cost for pipe construction or pumping station construction.

Conclusions

Considering the divergent sources of costing information and the time lag between the preparation of reports it can be stated that the basic costs of the different modes of transportation are comparable.

4. SENSITIVITY ANALYSIS AND STAGING OF SLUDGE ALTERNATIVES

In Section 3, the various sludge alternatives were analyzed under the constraints of current technologies and current federal and state policies. This section poses a set of potential changes in these conditions, and estimates their impact on the feasibility of the various alternatives. The changes are evaluated individually in the sections below, and include

Shifts in Costs and Prices

1. Revenue increase for sale of sludge, sale of corn, and sale of compost
2. Relative inflation in energy costs over all alternatives
3. Increased grant eligibility for co-combustion alternatives
4. Increased and decreased distance to ocean disposal and land utilization sites

New Technologies

5. Reduction in costs for sludge dewatering
6. Effective pretreatment program

Changing Standards

7. Odor control for combustion
8. Disinfection requirements
9. Standards for land application
10. Ocean disposal standards allowing sludge discharge or dumping

It should be noted that the sensitivity of cost per ton to system performance has already been implicitly carried out by means of the various cases and alternatives treated in Section 3. In addition, initial considerations for secondary sludge management are discussed in Section 4.11, inclusing issues such as land availability, ambient air pollution, availability of solid waste, and markets for compost and sludge.

Sections 4.12 and 4.13 close the sensitivity analysis with consideration of the potential for gaining flexibility, and the costs of such gains. One such option, considered in Section 4.12 is to split the sludge streams, handling Deer and Nut Island sludges in different ways, related to the individual sludge compositions. Another is to delay, and the final section explicitly considers the issues involved in delaying a decision: continued environmental impacts and costs from the present system, present value savings through delay, and expected gains in information about the alternatives.

4.1 Increases in System Revenues

The costs provided in Table 3.2-1 for the sludge alternatives depend on the revenues achieved from sale of specific products. For example, the combustion alternatives produce usable energy, land utilization options grow crops, and there is the possibility of selling compost to users. To analyze the sensitivity of system costs to these predicted revenues, we considered the following set of shifts:

- 50% increase in corn prices (or, alternatively, crop yields)
- sale of compost at $10/ton (given away or landfilled in the initial analysis)
- sale of sludge to farmers @ $10.00/dry ton

Shifts in corn prices or crop yields are more significant, as shown in Table 4.1-1. Here, net annual costs drop by $5-$8/ton with a 50% increase in corn prices or assumed yields. This is, at best, a reduction of about 10% in the net costs/ton for the MDC land utilization alternative.

If compost can be sold, the cost of composting drops significantly, from about $92/ton to about $81/ton. This is only reasonable -- a $1 increase in compost sale price/ton leads to about a $1 decrease in net cost/ton of the system. This may be significant enough to be worth further analysis, but it appears that the ability to give the compost

TABLE 4.1-1

IMPACT ON MDC LAND APPLICATION COSTS OF A 50% INCREASE IN CORN PRICES

Case	Revenues ($000/yr.)		Net Cost/ton		% Change in Net Cost/ton
	Before	After	Before	After	
9A	350	700	77.68	69.45	-10.6
9B	350	700	82.70	74.67	- 9.7
9C	250	500	136.80	131.07	- 4.2
9D	250	500	147.49	141.76	- 3.9

away is even more significant: Case 6B involved trucking half the compost to Plainville and paying landfill fees, and raised the cost by about $20/ton over the base Case of 6A.

The sale of sludge as a fertilizer substitute also leads to a direct decrease in net costs equal to the price per dry ton of sludge. Obviously, $1 of revenue per ton of sludge will just offset $1 per ton of MDC costs. The DPRA marketing study for Region I estimated a value of $20.84 per ton of sludge delivered and spread (DPRA 1975); if even half of this ($10/ton) could be achieved as revenue by the MDC, the net costs would be those in Table 4.1-2. These revenues, however, depend on the MDC's ability to find users for all the sludge. It is interesting to note that, from the MDC's viewpoint, it would be cheaper to build both pipelines and sell the sludge (8E) than to build one and give it away (8B).

Price shifts, then, do affect system revenues, but are not significant enough to be a major concern in the early stages of planning.

4.2 Analysis of Energy Costs

The relative direct costs of the various systems are fairly insensitive to the costs of energy. Table 4.2-1 shows the unit costs of all cases before and after an energy price increase of 100% (in constant dollars). The table also ranks the various cases according to cost under the two scenarios. The only major shift is in the co-pyrolysis system, where costs jump from $93 per dry ton to $145 per dry ton. Otherwise, while the costs of all alternatives rise, there are no major relative shifts and, therefore, no significant impact on the decision process. If energy costs are expected to change significantly in the future, however, it would probably be unwise to develop a co-pyrolysis facility. Note that the dollar impact on local costs would be the same as on national costs, since energy is a local O&M responsibility. Note also that these are only direct costs: energy costs also enter indirectly,

TABLE 4.1-2

EFFECT OF PRICING SLUDGE DISTRIBUTION IN DISPERSED SITE LAND APPLICATION

Case	No Revenues for Sludge Sales		Revenues of $10.00/ton	
	Cost/ton	Cost/ton for MDC	Cost/ton*	Cost/ton for MDC
8A	75.47	34.82	75.47	24.82
8B	124.97	46.93	124.97	36.93
8C	84.83	38.11	84.83	28.11
8D	134.30	50.22	134.30	40.22
8E	153.65	56.11	153.65	46.11

*No change: shift from consumer surplus (farmers) to government.

Table 4.2-1

100% INCREASE IN ENERGY COSTS AND REVENUES

Alternative	Case	Net Cost/Ton		Rank Over All Cases		% Change in Net Costs
		Before	After	Before	After	
Incinerator	1A	105.87	101.52	15	14	- 4.1
	1B	106.06	105.21	16	15	- .8
	1C	111.61	116.31	19	18	+ 4.2
	1D	121.33	130.75	22	23	+ 7.8
Pyrolysis	2A	109.63	105.83	17	16	- 3.5
	2B	115.48	122.52	21	20	+ 6.1
	2C	131.64	156.36	25	28	+18.8
Co-Combustion	3A	87.88	84.81	12	12	- 3.5
	3B	92.88	144.53	14	25	+55.6
Ocean Discharge	4A	17.33	19.95	1	1	+15.1
	4B	34.76	34.99	2	2	+ 6.6
	4C	44.88	46.56	3	3	+ 3.7
Ocean Dumping	5A	51.45	54.40	4	4	+ 5.7
	5B	58.58	62.18	5	5	+ 6.1
	5C	61.79	64.81	6	6	+ 4.9
	5D	68.92	72.59	7	7	+ 5.3
Composting	6A	92.46	96.48	13	13	+ 4.3
	6B	113.69	117.48	20	19	+ 3.3
Landfill	7A	109.82	113.67	18	17	+ 3.5
	7B	123.12	126.74	23	21	+ 2.9
Land Application at Dispersed Sites	8A	75.47	78.23	8	9	+ 3.7
	8B	124.97	128.27	24	22	+ 2.6
	8C	84.83	88.06	11	11	+ 3.7
	8D	134.30	138.09	26	24	+ 2.8
	8E	153.65	159.33	29	29	+ 3.7
Land Application at MDC Sites	9A	77.68	78.04	9	8	+ .5
	9B	82.70	83.06	10	10	+ .4
	9C	136.80	144.62	27	26	+ 5.7
	9D	147.49	155.56	28	27	+ 5.5

by affecting the prices of substitutes such as fertilizer and may, on balance, increase the attractiveness of land application.

4.3 Increased Grant Eligibility of Co-Combustion

Co-combustion facilities can be viewed in two ways: either they are solid waste facilities with added sludge handling, so that the marginal costs for sludge facilities are grant eligible; or, they are sludge handling facilities fueled by solid waste and thus totally grant eligible. The latter interpretation has been used in at least one California case, though it seems unlikely to be generally applicable. The impact resolving this question of grant eligibility is shown in Table 4.3-1.

If we assume that the sludge is an added component, then we are concerned with the incremental costs of sludge handling, and the solid waste portion of the facility is assumed to pay its own way. This is the base case, where we evaluated the costs of sludge handling, over and above those for a large-scale solid waste incinerator.

Alternatively, if the facility is built for handling sludge, solid waste is just a resource which may provide some useful revenue; in that case, the full facility costs should be applied to the sludge loading. Therefore, the total costs for sludge handling rise if the facility is assumed to be primarily concerned with sludge: we have to pay for the full costs of the boiler, the waste handling system, steam distribution, and the like. On the other hand, these costs become grant eligible, so that the local costs drop considerably. In fact, the grant eligible co-combustion options have a net local cost lower than for any other combustion case, and similar to the local costs of ocean disposal. Revenues for the solid waste burned would serve to reduce the local costs even further.

4.4 Impact of Transportation Costs

One of the major factors influencing the cost of sludge management is transportation. Deer and Nut Islands, like most regional wastewater

Table 4.3-1

IMPACT OF GRANT ELIGIBILITY ON CO-COMBUSTION UNIT COST/DRY TON OF SLUDGE

	Sludge Portions Only Eligible		Full System Eligible*	
Case	Incremental Cost	MDC Incremental Cost	Full System Cost	Full System Cost to MDC
Co-Incineration, 3A	87.88	65.52	124.79	25.02
Co-Pyrolysis, 3B	92.88	75.47	129.78	41.24

*Assuming no revenues from use of solid waste.

facilities, are downstream from the generators of the wastewater. In Boston, this means that they are on islands or peninsulas at the edge of Boston Harbor, and makes transportation costly. For most of the alternatives, transportation of the sludge to areas where it could be used requires construction of barge facilities or pipelines, and payment of barge rentals or docking fees at the shore.

Table 4.4-1 shows the cost/dry ton for transportation to the nation and to the MDC for each of the sludge management cases. It also shows the portion of total sludge management cost which is related to transportation alone in each case. Transportation is, as might be expected, most significant for the dispersed site land application alternative, where the sludge must be pumped to remote sites and then distributed to individual pieces of farmland: the only non-transportation costs are for sludge digestion at the plants. Transportation costs are least significant for the incineration, pyrolysis, and ocean options, where all the important activity occurs on Deer and Nut Islands. For the remaining options -- composting, landfill, land application at MDC sites, and co-combustion -- transportation costs range from about $30 to $50/dry ton, with the MDC portions in the $15 to $35 range. Transportation costs for these alternatives generally amount to about one-third of the total costs of the sludge management system.

It should be noted that the sensitivity of cost per ton to variations in transportation distance and mode has already been implicitly carried out, to some extent by means of the various cases and alternatives treated in Section 3. Also, variation in transportation costs due to a 100% increase in energy cost was included as a part of the sensitivity to energy costs in Section 4.2, above, and is not broken out separately here.

One of the major transportation costs comes from combining the Deer Island and Nut Island sludges. This pipeline costs about $14/ton in capital, and roughly $1 per dry ton for operations. It is necessary for alternatives such as incineration and pyrolysis, and desirable for land application where pipeline transport is used, but should be analyzed carefully for options such as composting, landfill, and the ocean alternatives. For example, separate composting facilities at Deer and Nut Island would have transportation costs of about $17/dry ton, rather than $32. Barge transports and terminal fees also amount to about $13/ton transported; it is possible that these costs could be reduced through the use of some other method, particularly at Nut Island or its replacement site where truck accessibility might be good. The potential

TABLE 4.4-1

TRANSPORTATION COST SENSITIVITY

Alternative	Case	Transportation Cost ($/dry-ton)	Percent of Total Cost	Transportation Cost to MDC	Percent of MDC Cost
Incineration	1A	22.20	21.0	7.80	14.6
	1B	22.20	20.9	7.80	14.9
	1C	22.20	19.9	7.80	13.5
	1D	22.20	18.3	7.80	11.5
Pyrolysis	2A	22.50	20.5	8.10	14.7
	2B	22.50	19.5	8.10	13.3
	2C	22.50	17.1	8.10	10.5
Co-Combustion	3A	30.50	34.7	29.28	44.7
	3B	30.50	32.8	29.28	38.8
Ocean Discharge	4A	1.33	7.7	1.33	11.5
	4B	30.74	88.4	5.30	56.9
Ocean Disposal	5A	6.69	13.0	5.47	17.3
	5B	8.83	15.1	7.61	19.7
	5C	21.78	35.2	8.00	23.8
	5D	23.92	34.7	10.14	24.9
Composting	6A	32.65	35.3	18.87	33.1
	6B	32.02	28.2	18.24	23.8
Landfill	7A	16.30	14.8	15.08	16.8
	7B	31.39	25.5	17.61	18.6
Land Application (dispersed)	8A	71.47	94.7	30.82	88.5
	8B	120.97	96.8	42.97	91.5
	8C	80.83	95.3	34.11	89.5
	8D	130.30	97.0	46.22	92.0
	8E	149.65	97.4	52.11	92.8
Land Application (MDC)	9A	37.90	48.8	9.15	54.7
	9B	37.90	45.8	9.15	51.8
	9C	48.76	35.6	35.01	42.9
	9D	48.76	33.1	35.01	38.4

reductions in transportation costs by these simple methods are as large, or larger, than many of the differences among technologies, and this suggests strongly that a careful analysis of transportation options should precede any decision about what technology is most appropriate. This conclusion is also supported by the differences among the analyses in Havens and Emerson, EcolSciences, and Section 2 of this report, where the mode of transportation is the basis for many of the cost differences in the land application cases.

4.5 Reductions in the Cost of Dewatering Sludge

One of the major areas of current research in sludge processing is the technology of dewatering. Several types of systems are being developed, and it appears possible that some significant cost reductions may take place in the near future. To analyze the sensitivity of our alternatives to this reduced cost of dewatering, we assumed simple a reduction in the O&M costs for drying of 30%. The results of this cost reduction are shown in Table 4.5-1, along with the revised rankings of our various cases.

Since these dewatering costs affect the combustion, ocean dumping, composting, landfill, and some of the land application options, the impact of savings is primarily to reduced overall costs, and the effect on relative rankings of alternatives is small. Ocean discharge still remains cheapest, though the margin is reduced, and land application is still competitive. The process choice seems relatively insensitive to the O&M costs for drying.

4.6 Pretreatment

Pretreatment of wastes entering the municipal system is included in P.L. 95-217 as one of the significant requirements affecting industries. The goals for the pretreatment program are numerous, but the major ones are

Table 4.5-1

30% REDUCTION IN DEWATERING O&M COST

		Total Cost $/Dry Ton		MDC Cost $/Dry Ton		Total Cost Rank	
		Before	After	Before	After	Before	After
Incineration	1A	105.87	98.37	53.38	45.88	14	14
	1B	106.06	100.06	52.33	46.33	15	15
	1C	111.61	105.61	57.87	51.87	18	18
	1D	121.33	113.83	67.59	60.09	21	21
Pyrolysis	2A	109.63	102.13	55.12	47.62	16	16
	2B	115.48	109.48	60.96	54.96	20	20
	2C	131.64	125.64	77.13	71.13	24	24
Co-Combustion*	3A	87.88	81.88	65.52	59.52	11	9
	3B	92.88	86.88	75.47	69.47	13	13
Ocean Discharge	4A	17.33	17.33	11.58	11.58	1	1
	4B	34.76	34.76	9.31	9.31	2	2
Ocean Dumping	5A	51.45	45.45	31.55	25.55	3	3
	5B	58.58	51.08	38.68	31.18	4	4
	5C	61.79	56.79	33.62	27.62	5	5
	5D	68.92	62.42	40.75	33.25	6	6
Composting	6A	92.46	86.46	57.03	51.03	12	12
	6B	113.69	107.69	76.61	70.61	19	19
Landfill	7A	109.82	103.82	89.92	83.92	17	17
	7B	123.12	115.62	94.95	87.45	22	22
Application - Dispersed	8A	75.47	75.47	34.82	34.82	7	7
	8B	124.97	124.97	46.93	46.93	23	23
	8C	84.83	84.83	38.11	38.11	10	11
	8D	134.30	134.30	50.22	50.22	25	26
	8E	153.65	153.65	56.11	56.11	28	28
Application - MDC	9A	77.68	77.68	16.72	16.72	8	8
	9B	82.70	82.70	17.66	17.66	9	10
	9C	136.80	130.80	81.62	75.62	25	26
	9D	142.49	134.99	88.62	81.12	27	27

*No cost reduction for rotary dryer, only for the vacuum filters.

- To make the industries pay their fair share of the costs of treating their wastes (this interacts with the user charge requirements)
- To enable the plants to operate correctly
- To reduce the discharge of dangerous and toxic materials.

Two types of materials -- metals, and toxic organic chemicals -- make it hard to use sludge as a resource. To be useful for sludge management, therefore, the pretreatment program should be effective in removing these materials before they enter the sewer system.

P.L. 95-217 sets specific standards for various types of waste treatment, and one of the jobs of this study is to determine whether these standards are reasonable, or whether other approaches would be more useful to the nation as a whole. We can analyze this for the metals entering the MDC system, since secondary treatment would result in removal of high percentages of metals (over 90%) from the effluent, and deposit those metals in the sludge. We are concerned with the relative costs of pretreatment versus use of high metal content sludge in our various sludge management alternatives.

Buffalo provides a model of an effective pretreatment program, and provides basic information on program costs to industry and the local government. Most of the research on pretreatment has concentrated on the electroplating industry, since the industry discharges high levels of metals, almost solely to municipal systems, and from small firms particularly sensitive to high pretreatment costs.

In Buffalo (Peck, 1977), the pretreatment monitoring program cost approximately 75¢ per capita annually for the region. These costs were borne by the local government. Electroplaters bore about 25% of the capital costs for pretreatment paid by all firms, and about 32% of the annual O&M costs, and the size distribution of electroplating firms was similar to

Boston's. An extensive national survey performed for EPA (Booz, Allen & Hamilton, 1972 indicated that about 48% of the firms in SIC codes 3471 and 3479 do not come under pretreatment regulations. Those firms which have installed a pretreatment system to remove most metals paid an average of $60,000 in capital costs, and $10,000 in annual operations and maintenance costs. Similar figures for the costs of treatment electroplating wastes were found in the Worcester, Massachusetts area (Pleatsikas,1977) and in the Buffalo study. There is evidence, however, that the firms in SIC codes 3471 and 3479 are only a portion of the industry: electroplaters are divided into "job" shops in those industries, and "captive" shops which are portions of larger firms. It appears that the captive shops are at least equal in number of the job shops.

There is little information about pretreatment costs to other industries, or about the costs of pretreatment of toxics or similar wastes. Based on the above assumptions, we can make a first estimate of the cost of a Buffalo-style pretreatment program as shown in Table 4.6-1. It is estimated from the Buffalo experience that this program would remove about 50% of the metals in the influent, and therefore in the sludge. These costs and efficiency estimates are likely to be highly inaccurate, perhaps by as much as a factor of three (in either direction). They are based on the best available data on local industries and pretreatment program costs, but these data are limited, because few significant pretreatment programs have been implemented.

The benefits of pretreatment are even more difficult to assess. We can say nothing here about toxics, or about the removal of metals from the effluent: those are beyond our scope. With respect to the combustion alternatives, removal of metals from the sludge would have little impact, since they do not form the most important air pollution standards for the alternatives. Metals removal would reduce pollution

Table 4.6-1

ESTIMATED PRETREATMENT COSTS ($000)

MDC Costs	Initial	Annual O&M	Total Annual Cost
(IWS and monitoring beyond UC/ICR requirement) (assuming no grant eligibility)	$ 1,368	$ 85	$ 214
Industrial	Capital	Annual O&M	Total Annual Cost
Electroplating Industry			
Per firm	$ 60	$ 10	$ 15
Times 62 firms*	$ 3,720	$ 620	$ 907
Industry-Wide Total (assuming electroplating is 33% of O&M and 25% of capital)	$14,880	$1,860	$3,165
Total	Initial	Annual O&M	Total Annual Cost
	$16,248	$1,945	$3,379

*Assuming 31 of 62 firms in SIC 3471 and 3479 need pretreatment, and that there are an equal number of captive shops.

residuals entering the air, but would have no effect from the perspective of the federal standard.

The land and ocean alternatives are much more sensitive to metals, which are the basis for most of the existing or expected federal standards. The impact of pretreatment on these options is discussed more fully below, in Sections 4.9 and 4.10.

Some of the institutional aspects of pretreatment are also worth mentioning here. The MDC has stated that they will await final federal pretreatment requirements before implementing their pretreatment program, because of competitive advantage. Their reasoning is as follows:

- Uncertainty about the level of final standards for all sectors make establishment of local regulations too risky. Enforcement would be difficult because industries are primarily concerned with Federal regulations
- Without federal standards, there is no national equality of pretreatment requirements
- Therefore, assume that there are areas where pretreatment is not implemented
- If the MDC require industries to pretreat, the industries will face increased costs
- Therefore, industries in the non-treatment areas will show a competitive advantage, and the Boston area will lose business

It is even possible that industries currently resident in the Boston area will move to areas where pretreatment is not required, to reduce costs. One weakness of this argument is that final Federal direct discharge guidelines do exist for most industrial sectors and compliance with the direct discharge requirements of P.L. 95-217 has been enforced widely: effluent quality standards for BPT are being met. For any industry with a significant portion of its firms discharging directly, the firms served by the MDC are receiving a competitive advantage now, because of the slow implementation of secondary treatment in the area. The existence of a few firms with no requirements because of the lack of pretreatment standards is unlikely to be significant is assessing competitive advantage.

For industries which primarily discharge to municipalities, the MDC's argument has more credence. These are industries characterized by small plants, low water use, and few effluents, for the most part. The most significant ones are sectors such as electroplating, and industrial laundries, where EPA has nationally been concerned with choosing a fair policy to all concerned. For small firms discharging concentrated wastes, the MDC's policy of "wait and see" is reasonable. However, there is no reason why the MDC could not initiate the monitoring phase of a pretreatment program, directed primarily at the larger dischargers from these industries, perhaps including firms over 50 employees and 50,000 gallons per day. These would be the firms currently being covered in the MDC industrial waste survey, and should probably be the first target of a pretreatment program, since there are no significant equity questions related to them.

4.7 Requirements for Odor Control

EPA and the State of Massachusetts have the option of requiring odor control for sludge incinerators, and may also require controls over hydrocarbon emissions. To analyze the sensitivity of combustion options to such proposed controls, a case was developed for the incineration alternative which includes an afterburner to raise furnace exhuast gas temperature to 1400°F. This case is otherwise similar to case 1B, and its characteristics and costs are shown in Table 4.7-1. The impact on costs is an increase of about 6%, and this magnitude of impact would be expected if the incinerator was initially designed to include an afterburner. Addition of an afterburner as retrofit would be considerably more expensive, since it would be more difficult to gain the heat recovery revenues in that situation. It is, therefore,

Table 4.7-1

ADDITION OF AFTERBURNER TO CASE 1B

	Base	With Afterburner
% solids in sludge	30	30
BTU/lb of combustible portion	11,080	11,080
Excess air	50%	50%
Fuel use/dry ton sludge*	2.9 gal oil/dry ton	40 gal oil/dry ton
Economic Data ($1000/yr)		
Annual capital cost	2,604	2,642
Annual O&M cost	2,354	3,028
Annual total cost	4,958	5,670
Revenue	332	780
Net cost	4,626	4,899
$/dry ton	106.06	112.11
$/dry ton to MDC	52.33	57.60
Emission Data		
Hydrocarbon emissions lbs/day	127	1.3
Particulate emissions lbs/day	166	166

*Based on 127.5 dry tons of sludge per day including chemicals.

important that the odor control issue be decided before the design is complete for the incinerator. Note that there would be a major reduction in hydrocarbon emissions.

4.8 Requirements for Disinfection

Some of the alternatives may be required to perform disinfection, in an attempt to control pathogens entering the ocean or soil. Electron-beam irradiation was included in the base case for ocean discharge (continued use of the existing system) because of the potential for sludge to enter Boston harbor. We have also analyzed the cost impacts of three other uses of the electron beam system for disinfection:

- with the long ocean discharge, case 4B
- with the southern dispersed site land application, case 8B (uncontrolled private sites)
- with the western dispersed site land application, case 8D (uncontrolled private sites)
- with both southern and western land application, case 8E (uncontrolled private sites)

Table 4.8-1 shows the cost impacts of this form of disinfection on these cases, which is on the order of $10 per dry ton, though only about $6 per dry ton in local costs. The ranks of these cases overall do not change significantly. While the cost impacts may be important both to the Federal government and the MDC, the impact on decisions are likely to be small.

4.9 Impacts of Proposed Land Application Standards

As discussed in Section 3, the major impacts of land application standards will be to make it easier for local governments (and their engineers) to choose land application as an alternative for sludge handling. The standards will provide a design rule, eliminate considerable local uncertainty (though with no impact on the real local

Table 4.8-1

COST/DRY TON OF DISINFECTION REQUIREMENTS

	Net Cost		Local Cost	
	Before	After	Before	After
4B -- Ocean Discharge	34.76	44.88	9.31	15.26
8B -- Land Application at Dispersed Sites	124.97	134.92	46.93	52.96
8D -- Land Application at Dispersed Sites	134.30	144.25	50.22	56.25
8E -- Land Application at Dispersed Sites	153.65	163.60	56.11	62.14

environmental risk), and make land application a much more realistic option for local governments than it is today.

However, it will also be necessary for the sludge handling facilities to meet the standards, and this may be costly. This analysis assumes a design rule of .5 kg/ha annually for cadmium, which affects the level of sludge that can be applied to the land each year. This design standard appears likely to be implemented by EPA for 1985, and is at variance with the base case of Section 3, which applied agronomic levels of sludge.

There are three ways that the MDC could meet these limits on cadmium: first, it could reduce the cadmium content of the sludge through a pretreatment program which was about 50% effective. The costs of such a program were discussed in Section 4.6.

Secondly, it could reduce the design loadings from about 10 dry tons per acre to 4 dry tons per acre each year, proportionately reducing the cadmium. For the dispersed site application, this would require 2.5 times as many acres, which is likely to be a significant constraint. For the MDC owned sites, it would also increase costs, as shown in Table 4.9-1.

Finally, the MDC could choose to continue its assumed earlier application rate, but monitor the crops to ensure that unacceptable levels of cadmium did not enter them. Soil and groundwater monitoring would also be required, well beyond the base case requirements. However, the risks of producing crops with cadmium levels which are too high may be significant; they require a probability estimate which must be based on expert knowledge of the particular sites, and thus should be the subject of research if such facilities are actually considered for design.

We have not included the monitoring option costs in the table at this time, though they could probably be developed. Monitoring is an option only with MDC owned sites, of course, while the other costs could be directly applied to the dispersed sites option.

Two results are apparent from this analysis: first, that pretreatment to remove metals is not cost-effective if the only goal is a cleaner

Table 4.9-1

COST IMPACTS OF LAND APPLICATION STANDARDS ($000)

	Base Case*	With Pretreatment**	Lower Application Rate
Annual Capital	2954	4386	5123
Annual O&M	784	2729	1016
Total	3738	7115	6138
Revenues	350	350	791
Net Cost	3389	6765	5348
$/dry ton	77.68	155.10	122.61
MDC Costs, $/dry ton	16.72	21.63	16.90

*MDC owned facility, 9A, without pretreatment.

**Local MDC cost plus estimated industry cost, from Section 4.6.

sludge for land application -- reducing the application rate is somewhat more reasonable, financially.* Second, the lower application rate has essentially no impact on the costs borne by the MDC, since the extra operating costs are offset by extra revenues, and the major impact is with respect to the capital cost of the firm-land owned by the system. The national system cost rises by about 40%, but the MDC cost stays the same. In other words, the increased costs arising from stricter standards would be borne almost entirely by the Federal taxpayer under the reduced application rate option.

Contrast this with the pretreatment option, where the cost increase would be borne either by the MDC (we have assumed that the Industrial Waste Survey would not be grant eligible, even though it would be a one-time expense) or by the area's industries, and it is apparent that the reduced rate option should be preferred by the local system.

4.10 Changes in Ocean Disposal Standards Allowing Sludge Discharge or Dumping

Legislation mandating an end of all ocean dumping of sewage sludge by December 31, 1981 was passed by the U.S. House of Representatives in October, 1977. Although this generally precludes any changes in the status quo as discussed in Section 2.5.2 there are two eventualities which might result in either a change in allowance of dumping or a change of the standards.

With the institution of industrial pretreatment programs, the sludge could conceivably be "clean" enough to meet the current ocean standards. For example, Deer Island sludge currently contains 70 ppm cadmium and 6.0 ppm mercury. The standards in the solid phase are 0.6 and 0.75 ppm respectively. For pretreatment to have an effect there would have to be a reduction of 99% in cadmium and 90% in mercury. Based on current technology, this degree of reduction is impossible and pretreatment will not make enough of an improvement to allow for continued ocean dumping.

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*While the pretreatment cost estimates were highly uncertain, they would have to be reduced by over 50% to make pretreatment nationally more attractive than the reduced application rate.

The standards might change should there be a change in the interpretation of "unreasonable degradation" of the environment. The interpretation could range from 1) considering economics uppermost and continuing to dump allowing for a greater degree of degradation of the marine biota to 2) considering preservation of the marine biota uppermost, allowing no detectable difference between the dumpsite and 'clean' areas and therefore being forced to choose a less cost-effective disposal option. If the first interpretation was used, the standards would be relaxed considerably since some degree of degradation would be allowed. In the second interpretation standards would be made even stricter to allow no detectable effects on the marine ecosystem.

The current standards lean toward the second interpretation of "unreasonable degradation." Given the regulatory climate in Congress, no flexibility in the ocean ban can reasonably be expected.

4.11 Secondary Sludge Considerations

While the bulk of the analysis included above has been concerned with the processing and disposal of primary sludge from the MDC system, secondary sludge management is also an important issue. The quantities, composition, and available options for secondary sludge are currently under study by EPA for the Environmental Impact Statement on proposed MDC treatment plants, which is under preparation.

This analysis has not attempted to explicitly estimate the costs of secondary sludge options in any detail, though the primary sludge alternatives proposed here are a useful basis for such estimates, and the final subsection considers the effects of various wastewater treatment alternatives. Instead, it has used the experience gained on the primary sludge analysis to help identify the major constraints facing secondary sludge processing. These constraints are of the following types:

- land availability at Deer Island
- land availability for land application
- landfill capacity limits

- availability of solid waste for co-combustion
- air quality requirements
- available markets for compost

4.11.1 Land at Deer Island

Three of the alternatives -- incineration, pyrolysis, and composting -- are assumed to use large amounts of land at Deer Island. About 438 dry tons/day of undigested combined primary and secondary sludge are projected for the proposed system in 1995, which means a fourfold increase in required processing capacity. The proposed layout for secondary treatment at Deer Island is shown in Figure 4.11-1. In this figure, land allocated to primary and secondary sludge comprises about 2 acres; while more land could be added by fill, this is expected to be a major issue in the environmental impact assessment. However, there is clearly enough land available for barge connections, dewatering systems, and the like.

Incinerators and pyrolysis systems are expected to be modular, and to require less than 1 acre for primary sludge management on Deer Island, and the secondary sludge requirement would be similar. They would fit, under the recommended plan.

The composting system needs about 40 acres for primary sludge, including storage of compost and wood chips, plus the composting area itself. For combined primary and secondary sludge composting, this would roughly double, and this land would either be found elsewhere, or through fill.

4.11.2 Land for Land Application

Table 4.11-1 shows the land requirements for the primary sludge options. Assuming the application rate stays the same (10 dry tons/acre per year), these requirements would rise according to the added secondary sludge. The resulting needs are shown in Table 4.11-2.

The southern route is obviously insufficient for land application of both primary and secondary sludge, since there are needs for over

Figure 4.11-1

DEER ISLAND WWTP -- RECOMMENDED

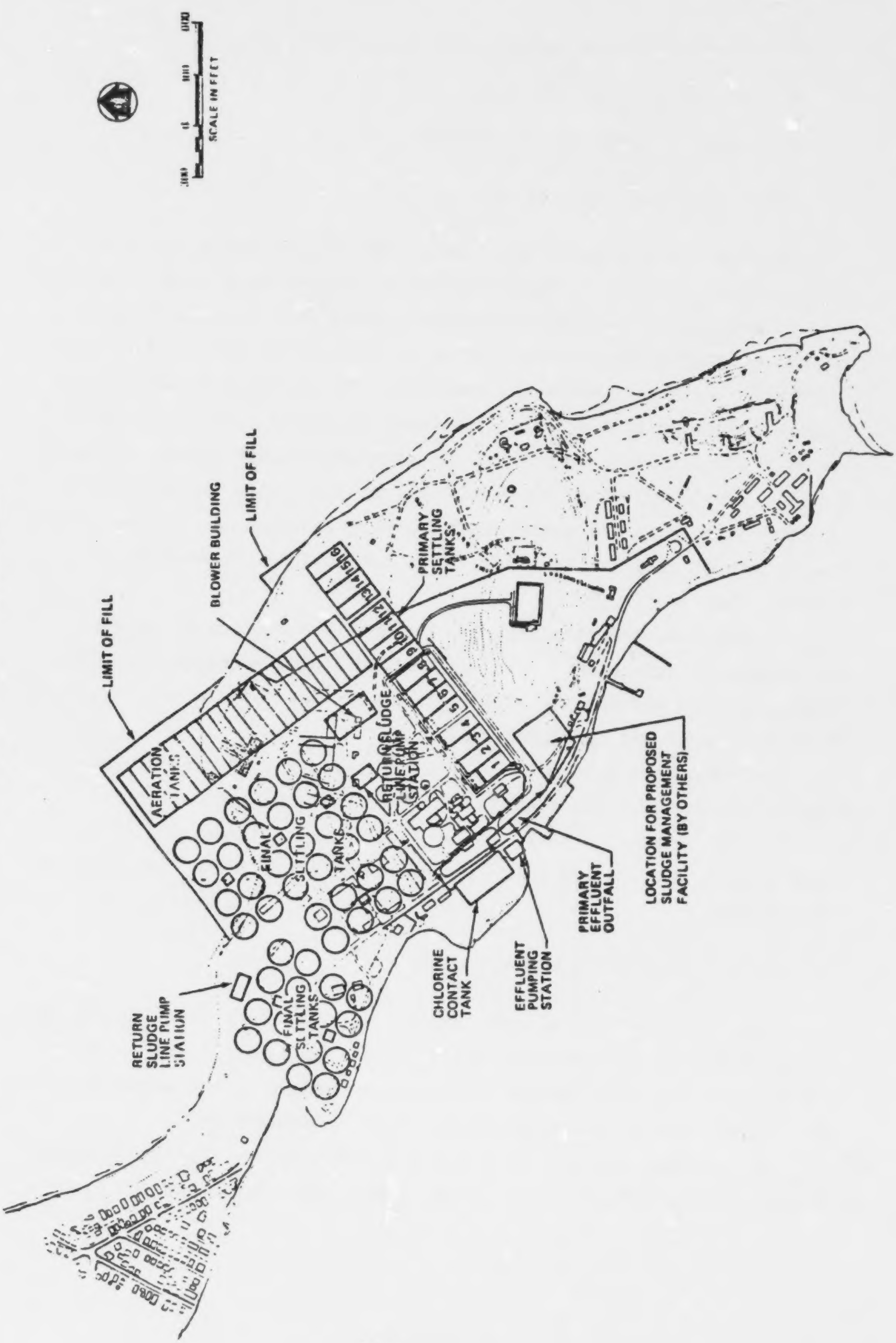

SCALE IN FEET
0
LIMIT OF FILL
LIMIT OF FILL
BLOWER BUILDING
PRIMARY SETTLING TANKS
AERATION TANKS
FINAL SETTLING TANKS
RETURN SLUDGE LINE PUMP STATION
RETURN SLUDGE LINE PUMP STATION
FINAL SETTLING TANKS
CHLORINE CONTACT TANK
EFFLUENT PUMPING STATION
PRIMARY EFFLUENT OUTFALL
LOCATION FOR PROPOSED SLUDGE MANAGEMENT FACILITY (BY OTHERS)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Table 4.11-1

PRIMARY SLUDGE LAND REQUIREMENTS

Alternative	Land Required	Buffer	Total	Land Available
8A	4380	none	4380	6,400
8B	4380	none	4380	6,400
8C	4380	none	4380	19,160
8D	4380	none	4380	19,160
8E	4380	none	4380	25,560
9A	4380	660	5040	*
9B	4380	660	5040	*
9C	3130	470	3600	*
9D	3130	470	3600	*

*Purchased as needed.

Table 4.11-2

LAND REQUIREMENTS FOR SECONDARY SLUDGE APPLICATION

Case	Land Required	Buffer	Total	Available
8A	16050	0	16050	6400
8B	16050	0	16050	6400
8C	16050	0	16050	19160
8D	16050	0	16050	19160
8E	16050	0	16050	25560
9A	16050	2420	18470	*
9B	16050	2420	18470	*
9C	11470	1730	13200	*
9D	11470	1730	13200	*

*Purchase as necessary.

16,000 acres, and only about 6,400 in use as farmland. However, the western or combined routes still seem feasible, if 84% or 63% of the farmers can be convinced to take the sludge, respectively. This appears to be an exceedingly high estimate for market penetration, but might be within the realm of possibility. If the application rate was reduced by metals standards, as discussed in Section 4.9 above, there would be insufficient land in Eastern Massachusetts for dispersed site application. It should be noted that combined sludge would be more likely to be accepted by farmers than primary alone, because of its higher fertilizer value.

The availability of 13,000 to 18,000 acres in the Plymouth area for combined land application of primary and secondary sludge is unlikely. It would be necessary to go further afield in locating land application sites, and this seems to be a reasonable solution: there is currently a great deal of concern in the state about the loss of agricultural land, and a major sludge utilization program would help make the region more self-sufficient. Land for land application at centralized sites appears to be available.

4.11.3 Landfill Capacity Limits

As described in Section 2, there appears to be limited availability of landfill capacity for primary sludge. It is clear that there is no capacity available in permitted landfills in Eastern Massachusetts for secondary sludge. For secondary sludge management, therefore, the MDC would have to develop its own acceptable landfill site. To provide a reasonable capacity for sludge to the year 2000, the site should be at least 700 acres (including buffer zones); it should be within about 40 miles of Boston to be economically acceptable.

4.11.4 Availability of Solid Waste

Co-combustion systems should have at least 10 tons dry weight of solid waste for each dry ton of sludge entering the system. Therefore, a co-combustion system for all of the MDC primary and secondary sludge would require about 4,400 tons per day of solid waste.

A facility in South Bay could probably draw on a population of about 1.5 million people, and on considerable amounts of commercial and industrial activity. We estimate the available solid waste to be about 6,000 tons per day at best; since much of this is handled by private haulers who would have to receive an acceptable contract before committing the waste to the facility, the 4,400 tons per day requirement would be difficult to achieve. However, it is possible, and co-combustion of secondary sludge should not be eliminated by this constraint.

4.11.5 Air Quality Requirements and Combustion Alternatives

Expected emissions of air pollutants would increase with the expansion of sludge incineration capacity and full use of Phase I incinerator capacity to accommodate increased quantities of secondary sludge and primary sludge after abandoning digesters. Assuming the NSPS particulate emission rate of 1.3 pounds per dry ton of sludge and a Phase II total secondary and primary sludge production rate of 438 dry tons per day, projected particulate emissions would increase from 30 tons per year to approximately 104 tons per year. Any particulate emission rate greater than 100 tons per year is a major source according to present EPA criteria (the criteria may be 50 tons per year in the future), and an emission offset would apparently be required before incineration capacity could be expanded.

As described previously, if Boston is designated as a non-attainment area for NO_2, an NO_x emission offset may also be required for expansion of incineration capacity.

4.11.6 Available Markets for Compost

It was assumed in Case 6A that all the compost produced from primary sludge could be given away, and in Case 6B that only 50% could be distributed, with the rest landfilled. While the compost market has not been studied carefully in this or preceding studies, the fertilizer market in the Massachusetts area has. In that study, the use of primary sludge for fertilizer was expected to be constrained by the available market, and that was the basis for our assumptions about primary sludge compost. (DPRA, 1975)

Secondary sludge compost may be of higher quality, but the added quantity will make it even more difficult to distribute. While the data are not available to eliminate this alternative (and, in fact, the market for primary compost appears strong), it would probably be desirable to analyze the market much more carefully before committing to it.

4.11.7 Conclusions of the Sensitivity Analysis

This section simply attempted to identify and describe the major constraints on secondary sludge management, assuming use of the technologies described above for primary sludge. The most significant constraints are probably on land application, since land availability is a major problem. Landfill and composting are also constrained, by land availability and by a lack of suitable landfill sites or compost users. The combustion options are relatively unconstrained, and the ocean options fall under the same Federal environmental limits as affected primary sludge disposal.

4.11.8 The Kennedy Engineers' Wastewater Treatment Alternatives: Relationship to Sludge Management Planning.

Kennedy Engineers, Inc., presented a technical review of the wastewater treatment facilities recommended in the EMMA plan and developed 14 additional wastewater treatment alternatives. The wastewater treatment plans evaluated by Kennedy Engineers are grouped as follows:

Category I:	Baseline Conditions
Category II:	EMMA recommended plan
Category III:	KEI alternatives

The projected sludge quantities for the year 2000, as provided by Kennedy Engineers, were presented above in Table 2.2-2. Brief descriptions of the facilities considered in each Kennedy alternative are presented in Appendix 2A to Section 2 of the study. The four Category I alternatives are based upon variations of the assumed population served, per capita flow allowances, and methods of handling intermittent wet weather flows at Deer Island and Nut Island. All Category I alternatives include only primary treatment at existing Deer Island and Nut Island facilities, with some rehabilitation of these facilities. There are no inland advanced wastewater treatment (AWT) plants in Category I.

With respect to sludge production, Category II is the EMMA plan as recommended, including secondary treatment at Deer Island and Nut Island plus AWT plants at middle Charles and upper Neponset locations.

Kennedy Engineers presents 10 alternatives for wastewater treatment in Category III, which range from primary treatment only at Deer Island and Nut Island (with harbor discharge of primary effluent) to secondary treatment at Deer Island and Nut Island plus inland satellite lagoon treatment plants. Category III alternatives are based on the service area and flow allowances as used in the recommended EMMA plan.

The study management alternatives developed in detail by ERT are based specifically on the Havens and Emerson -- EPA Draft EIS projections of 439,000 lbs. of raw primary dry sludge solids (DSS) per day requiring treatment and disposal (i.e., 239,000 lbs. DSS per day after anaerobic digestion in existing digesters). As shown in Table 2.2-2, the Kennedy alternatives are projected to produce raw sludge quantities requiring treatment and disposal which range from a low of 328,000 lbs. of primary DSS per day for alternative IA to a maximum of 818,000 lbs. of combined primary and secondary sludge DSS per day for Alternative II (EMMA Plan). In addition to the range of sludge quantities requiring treatment and disposal, many Kennedy alternatives in Categories II and III involve production of sludge at inland sites away from Deer Island and Nut Island.

Therefore, the specific unit costs developed by ERT in this study (as part of the analysis of the planning process which resulted in the selection of the MDC-EPA recommended sludge plan) cannot be directly applied to each Kennedy Alternative to calculate a comparable range of sludge disposal costs. Construction of a 15 by 28 cost matrix, which would be required to evaluate sludge management plans for all Kennedy alternatives in comparable detail, is beyond our scope of work and unnecessary for policy analysis. However, certain aspects of the sludge management planning process identified in this study provide insight into the relative impact of sludge disposal options on the Kennedy alternatives. The major question is whether selection of a sludge disposal method can alter the feasibility of any Kennedy alternative.

Kennedy Engineers' Category I

The four wastewater treatment alternatives in Kennedy's Category I are most similar to the sludge disposal situation considered in this study. Projected total raw primary sludge quantities from Deer Island and Nut Island are compared below:

H&E -	EPA	1985	439,000 lbs. DSS/day primary
KEI	IA	2000	328,000 lbs. DSS/day primary
KEI	IB	2000	360,000 lbs. DSS/day primary
KEI	IC	2000	425,000 lbs. DSS/day primary
KEI	ID	2000	539,000 lbs. DSS/day primary

The primary treatment provided by Category I alternatives result in year 2000 daily primary sludge quantities comparable to H&E-EPA 1985 projection because of restricted service area and lower per capita flow allowances assumed by Kennedy. KEI alternative ID includes additional solids collected from treatment of some combined sewer overflows.

The range of unit costs for various sludge disposal options developed in this study (see Table 3.3-1) would be generally applicable to Kennedy's alternatives IA, IB, IC and ID, if digestion is maintained, recognizing that some variations due to economies of scale may result for slightly higher or lower sludge quantities. Unit costs would be increased for maintenance of digesters through the year 2000. Ocean disposal of treated sludge would again be found most economical if allowed; combustion and land application sludge disposal alternatives would be roughly equivalent in cost with selection depending on decisions regarding technical and policy uncertainties as discussed in this report.

Kennedy Engineers' Category II

Category II is the EMMA recommended plan which includes secondary sludge generated at Deer Island and Nut Island plus sludge from AWT plants at two inland locations. For alternative II (EMMA plan), the projected year 2000 average daily raw sludge quantities are as follows (Kennedy 1977):

Deer Island	478,000 lbs. DSS/day	primary & secondary
Nut Island	210,000 lbs. DSS/day	primary & secondary
Upper Neponset	58,000 lbs. DSS/day	AWT
Middle Charles	72,000 lbs. DSS/day	AWT
Total:	818,000 lbs. DSS/day	

The total quantity of raw sludge produced in roughly twice the amount considered in the EPA draft EIS on primary sludge and this study. Also, because anaerobic digestion capacity at Deer Island and Nut Island would be either expanded or abandoned and because the composition and site of generation of AWT sludge are different from the baseline used in this study, the unit costs presented in Table 3.3-1 are clearly not applicable to Alternative II, except as order of magnitude estimates for sludge disposal costs for Deer Island and Nut Island sludge only.

The combined sludge total for Deer Island and Nut Island of 688,000 lbs. DSS/day requiring treatment is less than the 819,000 lbs. DSS/day projected by H&E for the two inland plants for 1995. Thus, the Phase II sludge facilities originally planned for Deer Island by H&E (H&E 1973) need to be revised even if incineration is retained as the recommended plan. Because the EMMA plan merely adopted the H&E sludge management costs, presumably it will be left to EPA's EIS on secondary treatment facilities (now in preparation) to complete the sludge facilities planning for Phase II. On the basis of this study, the full range of sludge disposal options should be considered for secondary sludge. However, as discussed previously, there does not appear to be sufficient land available at Deer Island for composting of the combined primary and secondary sludge from Deer and Nut, and the land requirement for land application becomes substantial.

The technical and policy issues identified in this study with respect to the various sludge disposal options are generally applicable to evaluation of sludge management plans for inland AWT plants; however, the specific unit costs are not applicable. It should be noted that the EMMA plan simply assumed for its cost analysis that sludge incineration would be selected for the inland AWT plant, though the findings of this study indicate that the full range of sludge disposal options should be considered in actual facilities planning. The EMMA report agrees, stating that "before final design is undertaken", sludge management techniques at these AWT plants should be reviewed, including incineration, co-incineration with solid waste, and landfill. Although not mentioned, composting, land application and ocean disposal should also be evaluated. It is clear that the inland plants may be more advantageously located for composting or land application but, should ocean discharge be allowed in the future, inland plants would be at a disadvantage.

A specific issue not considered in this report is the composition of AWT sludge and what effect it can have on disposal options. The greater chemical content in the sludge could make the sludge less desirable for compost or land application, but it could also increase the unit cost of incineration due to increased ash disposal costs and extra energy required for heating of lime or other non-volatile, inorganic chemicals.

Kennedy Engineers' Category III

Kennedy's wastewater treatment Alternatives IIIJ and IIIK propose only primary treatment at Deer Island and Nut Island without AWT plants. The projected year 2000 primary sludge quantity for these two cases is 464,000 lbs. DSS per day, which is comparable to the 439,000 lbs. DSS per day used in EPA Draft EIS and this report for 1985, assuming that digestion capacity is maintained. Alternative IIIJ proposes deep ocean discharge of primary effluent beyond the Graves. If sludge could be discharged with this effluent, a low sludge disposal cost comparable to that of Case 4B of this study could be realized.

Kennedy Alternatives IIID and IIIG propose secondary treatment at Deer Island and Nut Island plus inland lagoon treatment plants. The inland lagoon treatment plants would produce only small quantities of sludge, suitable for give-away programs. For these alternatives and Alternative IIIA (which provides all secondary treatment at Deer Island and Nut Island with no inland plants), sludge management planning is required only for the combined sludge from Deer Island and Nut Island in the following quantities:

KEI	IIIA	2000	768,000 lbs. DSS/day primary & secondary
KEI	IIID	2000	688,000 lbs. DSS/day primary & secondary
KEI	IIIG	2000	688,000 lbs. DSS/day primary & secondary

The unit costs for sludge disposal options developed herein are not applicable to these alternatives, except as order of magnitude estimates.

Secondary sludge considerations discussed in this report are again pertinent. Composting and, perhaps, land application would be more attractive at the inland sites because of smaller sludge quantities and reduced industrial input of toxic substances. Presumably, land for composting could be found adjacent to or near proposed inland plant sites. However, the proposed sites are not rural, so land application would be some distance from the plant site. Local residents might also object to onsite composting of sludge, but it is unlikely that sludge incinerators would be more welcome.

Kennedy's Alternative IIIH would locate a large (56.2 mgd) AWT plant on the Neponset River which would generate 130,000 lbs. DSS/per day. Secondary plants at Deer Island and Nut Island would produce an additional 688,000 lbs. DSS/per day on the islands. Unit costs developed in this report are not applicable to this case.

In general, the technical and policy issues identified in this study are pertinent to the evaluation of sludge management plans such as those proposed by Kennedy Engineers Inc. for the Boston Case Study. Specific unit costs will vary, however, because of differences in transport modes and distances and economies of scale. The latter issue is particularly important for incinerators.

Generally, the selected wastewater treatment plan will determine the factors which most influence sludge management, i.e., sludge quantity, sludge quality and facility proximity to ultimate disposal sites. The satellite lagoon treatment plants proposed in two Kennedy alternatives (IIID,G) represent a special situation in which the need to choose a sludge disposal method is virtually eliminated for inland plants. Also, the Kennedy Alternative IIIJ presents a unique opportunity for low cost sludge disposal via discharge to the ocean, if allowed. Sludge management planning does not appear to limit the feasibility of any Kennedy alternative nor to dictate treatment facility design; however, it is clear that advantageous location of treatment facilities near ultimate disposal sites can reduce sludge disposal cost.

4.12 A Hybrid Alternative

It is clear that any decision made by the MDC would be subject to significant risk at present. For combustion, the major risks are whether the technology would work as planned; for landfill, the risks are whether the landfill capacity will be available for land application, the risks are related to Federal standards and perhaps to markets for sludge and compost; for ocean discharge or dumping, the potential is that the Federal regulations might change, allowing these low cost alternatives.

One way to reduce risks is to "keep your options open" by choosing more than one alternative for the short term. This may require paying a premium, since economies of scale exist with respect to sludge management alternatives. However, it would also allow further tests of the feasibility and actual operation of more than one of the available alternatives. For example, the Nut Island sludge is relatively clean and could be applied to land fairly effectively at present; the Deer Island sludge has much higher metals content, and could be landfilled in the short term. This would allow the MDC to test land application without committing to it.

The 28 cases presented in Section 3.1 assume the same management alternative will be selected for both Deer and Nut Island sludges. However, the possibility of implementing separate alternatives for each treatment system should be considered simply because of the fact that two different sewerage systems are involved. In this regard, the composition of Deer Island and Nut Island sludges is significantly different (see Section 2.2.2). Combining the two sludges could induce a benefit by diluting the heavy metals in Deer Island sludge. Conversely, Nut Island sludges are degraded resulting in more difficulty in implementing land utilization options. Combining sludges requires pipeline transport across Boston Harbor. The capital expenditure for this transport mode creates inflexibility in planning for secondary sludge. Finally, handling smaller quantities of sludges may provide greater flexibility in selecting alternative plans.

The systems presented here are basically similar to those presented in Section 3.1 with some modifications. Liquid land application (case 8A) was selected for the higher quality Nut Island sludge. However, a train transport mode was substituted for the pipeline transport in case 8A. This reduces capital and increases O&M costs. For Deer Island the heavy metal composition of the sludge was assumed to preclude land application or composting alternatives. In order to prevent excessive capital expenditures, combustion alternatives were not considered. Therefore, the most cost-effective landfill alternative was selected with proper consideration of available capacity at the Plainville site.

The emphasis on O&M costs provides obvious flexibility in future sludge management planning. In addition, both selected plans are reversible, should future technological changes provide more cost-effective alternatives. Therefore, the purpose of this hybird alternative is to provide an option which is currently cost-effective, and flexible with respect to future sludge management planning and implementable based on current knowledge.

Nut Island -- Subsystem (A)

The Nut Island portion consists of the land application of liquid digested sludge at Plymouth County sites owned and operated by the MDC. The use of train transport as opposed to pipeline transport changes the relationship between annual capital and annual O&M costs as shown by comparison with Table 3.1-1. However, the overall unit cost for case 8A and Nut Island -- Subsystem (A) is the same. Land requirements are reduced to a total of 2,000 acres of which only half will require clearing based on the availability of cleared land in southeastern Massachusetts. The cadmium load based on a 36 ppm concentration is liquid digested sludge and a 10 DT/acre/year application rate is 0.72 lb/acre/year or 0.86 kg/ha/year. This cadmium loading would be acceptable until 1985, but after 1985, loadings would have to be reduced to 0.5 kg/ha/year according to proposed EPA regulations.

Deer Island -- Subsystem (B)

The landfill option for Deer Island is essentially the same as case 7A presented in Section 3.2, except that only Deer Island sludges are considered. The reduction in unit cost is due to the climination of the need to transport Nut Island sludge to Mystic Terminal in case 7A. In addition, based on current permits and requirements, the Plainville facility does have capacity to dispose of Deer Island sludge (see Section 2.4.3).

The cost summary for this hybird alternative is presented in Table 4.12-1. Table 4.12-2 compares these costs to the costs of landfill the proposed disaggregate systems. It is important to note one significant added cost for flexibility: the Nut Island sludge is transported

Table 4.12-1

COST SUMMARY FOR THE HYBRID ALTERNATIVE

	Item	Unit	Cost
SUB-SYSTEM (A) - Nut Island			
	Total Capital	$	11,934,000.
	Annual Capital	$/yr	922,000.
	Annual O & M	$/yr	472,500.
	Total Annual[1]	$/yr	1,394,500.
	Unit Annual[2]	$/DT	83.97
SUB-SYSTEM (B) - Deer Island			
	Total Capital	$	5,589,000.
	Annual Capital	$/yr	522,100.
	Annual O & M	$/yr	2,314,900.
	Total Annual	$/yr	2,837,000.
	Unit Annual [3]	$/DT	105.04
TOTAL HYBRID ALTERNATIVE			
	Total Capital	$	17,523,000.
	Annual Capital	$/yr	1,444,100.
	Annual O&M	$/yr	2,787,400.
	Total Annual	$/yr	4,231,500.
	Unit Annual	$/DT	97.01

1. Crop Credit = 80 $/Crop Acre = 3.04 $/DT
2. Based on 45.5 DT/Day
3. Based on 74 DT/Day

Table 4.12-2

COMPARISON OF HYBRID COSTS WITH EARLIER CASES

	Hybrid	7A	9A
Total Capital Cost	17,523	10535	39608
Annual Capital	1,444	964	2954
Annual O&M	2,837	3826	784
Total Annual	4,281	4790	3738
Revenues	50	--	350
National Annual	4,231	4790	3389
Net Cost $/Dry Ton	97.01	109.82	77.68
MDC Cost $/Dry Ton	67.22	89.92	16.72

by train, rather than by pipeline, to reduce the capital cost and the level of committment. If land application does not work, it is assumed that the Nut Island sludge will be landfilled (at least until an alternative such as incineration is implemented); on the other hand, if land application works well, a pretreatment program could be implemented and the Deer Island sludge added to the system.

The MDC pays a significant premium over land application to keep these options open: on the order of $50/dry ton local costs, primarily because of the use of train transport and the landfill charges. The premium in total cost is much smaller, because of the difference in capital and O&M costs between the hybrid and the land application option. However, this premium may be a reasonable price for the reduction in risk from a failing land application program, at least from the viewpoint of the local decision - makers.

4.13 Staging

It has been assumed throughout that the MDC and EPA are concerned with making a decision in the near future, and that the requirements of P.L. 95-217 force such a decision to be made. Inclusion of the primary sludge incinerator in the Emergency Compliance Schedule Letter issued by the EPA to the MDC supports this assumption, as does the structure and legislative history of both P.L. 92-500 and P.L. 95-217.

However, it is also important to be concerned with potential changes in P.L. 95-217 and the construction grants program, particularly when such changes would lead to decisions which are in the national interest. Therefore, the analysis includes not only what decisions get made, but also when and how they should be made. If increased flexibility and even delay lead to better solutions, a change in the Federal programs may be desirable.

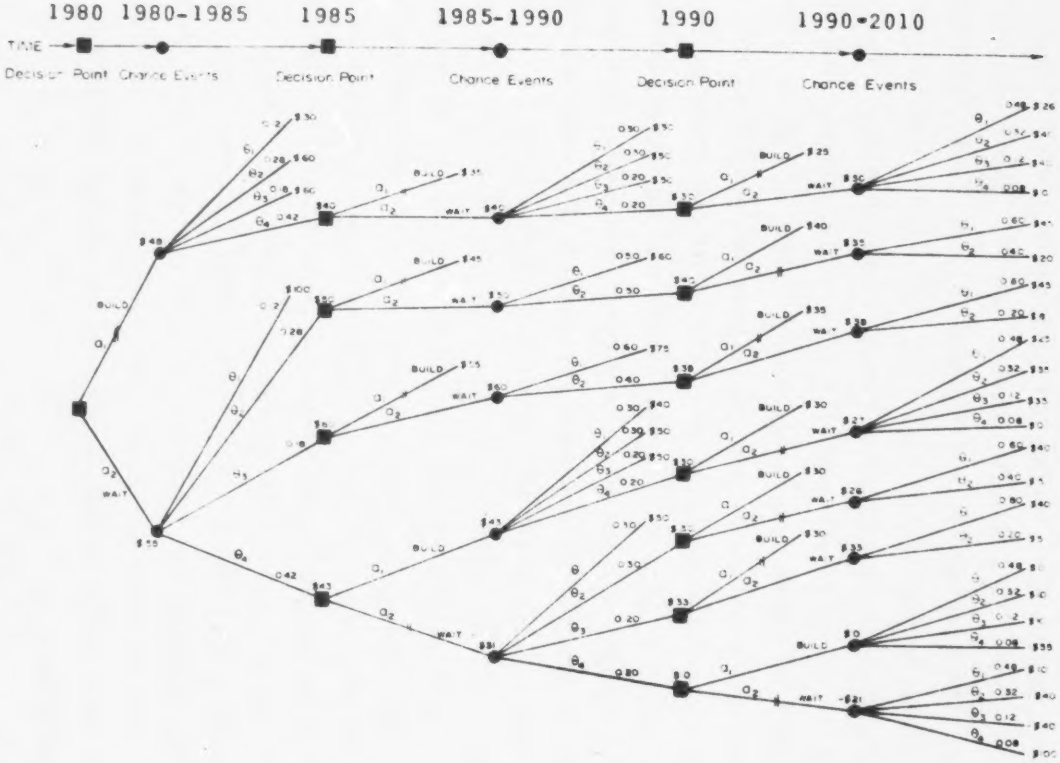
Public works facility planning can be viewed as a sequential decision process, where decisions are made at various points in time, and their consequences follow. A "myopic" decision rule is one which only considers the current situation: for example, one myopic rule would be to choose the option with least cost under the present situation (ocean discharge) without any consideration that it might be eliminated as an option in the near future.

A better approach would be to consider all current information about the future, and to structure the analysis to choose the options which will be most rational in the long term. For example, assume that planners consider a thirty-year planning horizon, with major decision points in 1980, 1985, and 1990. The alternative actions at each of these points are action a_1 -- begin construction of one of the incineration options; action a_2 -- delay for five years the construction of major new facilities. To simplify, assume that the major sources of uncertainty are the success (S_1) or failure (F_1) of land application alternatives at an "economically feasible" cost level, and the success (S_2) or failure (F_2) of on-going and future research efforts to find ocean disposal to be an environmentally acceptable option. The success of either or both of these alternatives would greatly reduce or perhaps eliminate reliance on extensive new facilities for incineration. The decision-makers are faced with the possibility of two types of errors. If they construct the incineration facilities and land application or ocean disposal becomes successful, the project may become a white elephant. If they do not build, and land application and ocean disposal fail, there will be severe environmental consequences.

An analysis of this decision is shown in the decision tree of Figure 4.13-1, with probabilities applied to the success or failure of land application. While the actual results are not our concern, it is important to note that waiting may lead to higher benefits in some cases, and that an analysis structured into such a decision tree can consider both current and projected future situations. While a thirty-year analysis of these alternatives would be unrealistic at present, given the numerous uncertainties in the system, a more limited evaluation of the decision to delay can provide important information about how national planning for wastewater and sludge management should be performed.

Figure 4-13.1

HYPOTHETICAL SLUDGE DECISION TREE


1980
1980-1985
1985
1985-1990
1990
1990-2010
TIME
Decision Point
Chance Events
Decision Point
Chance Events
Decision Point
Chance Events
BUILD
WAIT

θ_i = probability of path occurring. Figure adapted from Rausser & Dean (1975).

Source: Reference 6

4.13.1 The First Design Point

Let us consider what a five-year delay in the committment to a major alternative would mean:

- use of a temporary option, such as landfill, beyond 1981 when ocean discharge becomes illegal*
- no local experience with large scale sludge management facilities, which would be applicable to the secondary sludge decision
- increased information about the operation of combustion options
- increased information about land application standards
- potential changes in EPA grant eligibility, or limits on available funds for construction (because of the requirements of the remainder of the proposed EMMA plan)
- potential shifts in the ocean disposal or ocean dumping regulations
- potential implementation of a pretreatment program
- shifts in costs because of relative inflation, new technologies, and the like; and
- shifts in the available markets for sludge and compost

Other changes might also occur over time, but these appear to be the most likely ones. In essence, we are trading off the costs of the low-committment options versus the information to be gained over the next five years about the more capital-intensive ones. The current costs may be either environmental (ocean discharge) or economic (landfill) but they apparently exist. The information gains could be extremely significant, particularly with respect to the land application standards and the performance of the newer types of incinerators.

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*assuming the ocean discharge standards reflect the intent of Congress in eliminating ocean dumping

The question of whether delay is beneficial can be addressed as a case of sequential decision analysis. We are interested in determining whether it makes sense to pay the extra costs of avoiding a decision now, with the hope of making sufficient gains over the next five years to allow a better decision.

In the simplest case, for example, we might have the choice of building an incinerator now, or of sending the sludge to landfill for the next five years, and then building the incinerator. If we are just concerned with costs, we would find that the net present value of building the incinerator now was about $69 million (assuming an equal probability of achieving each of 1A, 1B, 1C, and 1D cases), while the net present value of delaying five years and then building the same incinerator would be about $74 million. Therefore, delaying would lose us about $5 million.

However, if incineration costs fell because of improved design, or if we gained confidence about our ability to design an incinerator which would meet the specifications, we might be able to save money. For example, if the five-year delay enabled us to build uncertainty case 1A with certainty, this would have a net present value of $71 million, or only $2 million more than we would pay for committing to incineration now, on the average.

There are three prime candidates for change: improved data on incineration systems, standards for land application, and a lifting of the ban on ocean dumping or discharge. As described in Section 2, there is little information to suggest how well the new types of incinerators will work in municipal, full-scale systems; the same is true for pyrolysis. However, such information should be developed over the next few years, and we will have sufficient data on both the dewatering and combustion steps to determine whether the systems can actually operate at or near design standards.

With land application, the question is not whether the systems will operate correctly -- that has been demonstrated in a number of locations. The real concern is related to Federal standards, which should soon be proposed and which could have a significant impact on land application system designs and costs. Also, experiments could be run during the five year period to test whether farmers would accept sludge or compost, to analyze metals uptake from Deer Island sludge, and to analyze the expected lengths of sludge application periods (60 to 120 days). These experiments, and the Federal regulations, would greatly reduce the uncertainty of land application, and allow a rational design to be developed for analysis and choice. A program of delay and experiment seems likely to make land application considerably more certain, and probably more attractive.

Ocean dumping and discharge are up to the Congress. At present, prohibitions are in the works, and continued ocean discharge appears unlikely to be allowed. However, this could change, and five years of delay might be sufficient to allow real information to be gathered about the local environmental impacts of the sludge discharge. If the MDC and EPA were able to prove that the impacts of the discharge were small, this would make a convincing case for an exemption. At present, the probability of continued ocean discharge seems low, but the economic advantages are so large that a delay to gain further information on the environmental costs could be useful.

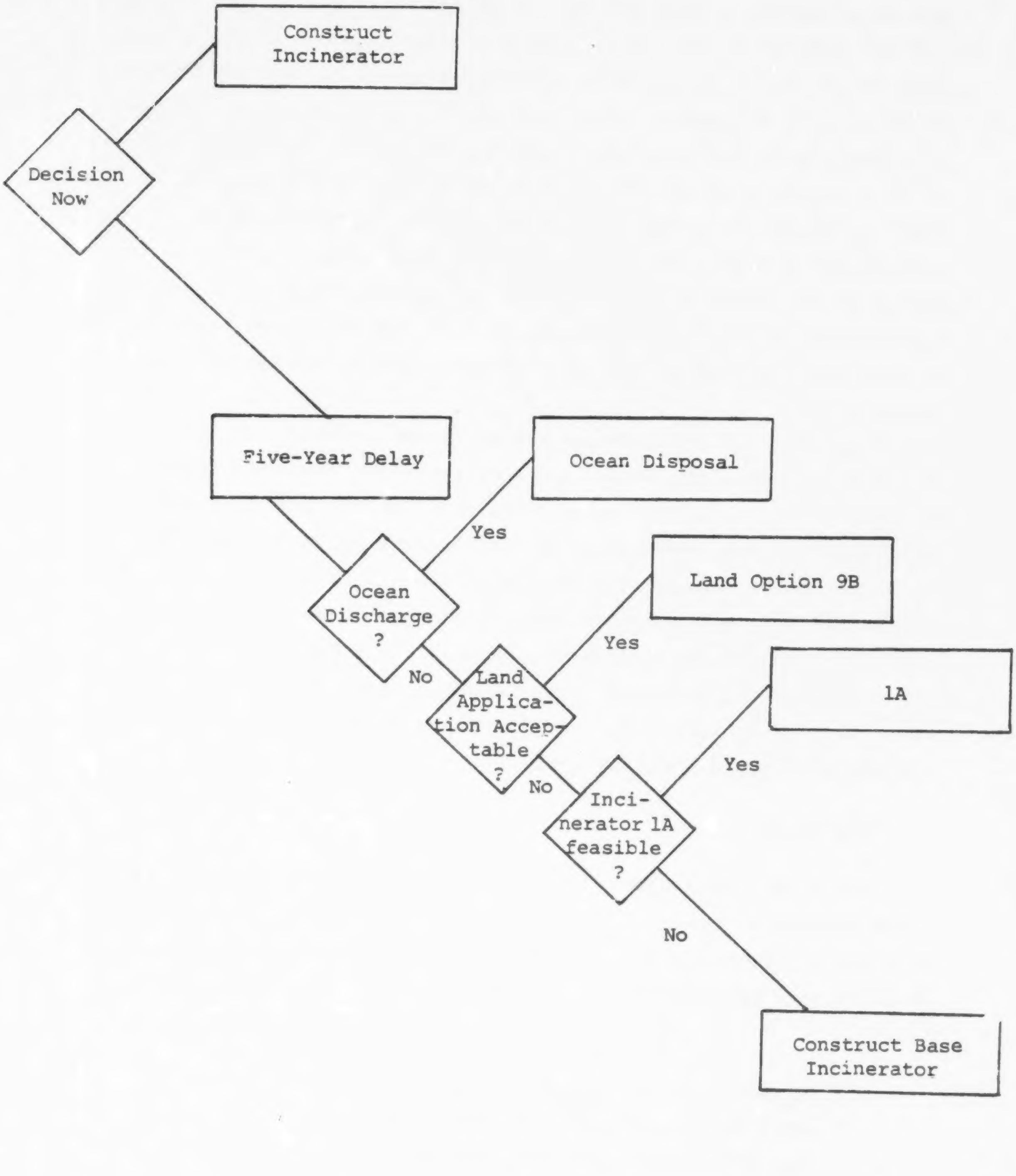
The Analysis

The basic analysis uses the decision tree shown in Figure 4.13-2, which includes a number of areas where change is likely over the next five years. There are a number of assumptions made in choosing this decision tree and structuring the analysis, which must be described here:

1. If the decision is made to construct a sludge management facility now, the MDC would choose incineration. Incineration performance, however, would be uncertain,

TABLE 4.13-2

DECISION-TREE FOR FIVE YEAR DELAY


Construct Incinerator
Decision Now
Five-Year Delay
Ocean Disposal
Yes
Ocean Discharge ?
No
Land Option 9B
Yes
Land Application Acceptable ?
No
1A
Yes
Incinerator 1A feasible ?
No
Construct Base Incinerator

and cases 1A to 1D from Chapter 3 show the range of potential performance. There is an equal probability of achieving each case if the incinerator is built.

2. If the option to delay is exercised, landfill case 7B would be implemented for five years. This case would be chosen because it combines sludge from Deer and Nut Islands, which is a prerequisite for the other alternatives.
3. In five years, there is a potential for any of the following three things to happen:
   - Ocean discharge might become acceptable, allowing implementation of case 4A
   - The MDC might become willing to commit to a land application system, given promulgation of Federal standards and guidelines (Case 9B becomes acceptable)
   - Further improvements in dewatering system operation and incinerator experience might make it certain that the incinerator would perform with the characteristics of incinerator case 1A.
4. However, none of these might occur: in that situation, we would gain no information, and be left with the original situation (aside from the costs incurred for the five years of landfill).
5. The discount rate is assumed at 7% per year, for a municipal facility, and there is no relative inflation over the period; Federal regulations and other economic factors remain unchanged.

We are concerned, then, with the probabilities of each of the events listed in #3, above, occurrring. We are also concerned with the costs of each of the cases of interest, as shown in Table 4.13-1. Table 4.13-2 summarizes our decision rule for the various future cases. If ocean disposal is acceptable, for example, we have assumed that the MDC would take advantage of its lower costs and choose that option; the same is true for land application, and for construction of the ideal incinerator, 1A. We have assumed that a decision is required in five years, so that (if the other options fail), the committment will be made to the currently planned incinerator.

Let us design an initial set of probabilities and see whether delay makes sense:

- probability of ocean being allowable: 2%
- probability of land application being feasible for the MDC: 20%
- probability of being able to build the incinerator to design specifications: 50%

With these probabilities, the Net Present Value (NPV) of the delay alternative is $70.4 million, and (since this is higher than the current NPV cost of $69.3 million) delay is not worthwhile. The decision tree for this case is shown in Figure 4.13-3.

Other probabilities can easily be assessed, and it is possible to learn which factors are critical to the analysis. For example, it is possible to determine how significant the ocean discharge option is in the evaluation. The break even point, where the MDC should be indifferent between constructing its incinerator now and delaying in the hope that ocean discharge would become acceptable, is about 6%. Therefore, if the MDC feels that there is a greater than 6% chance of ocean discharge becoming acceptable within five years, it should undertake temporary alternatives in the interim and hope that the ocean option becomes acceptable.

This analysis also has implications for research: if the MDC currently placed a probability of 2% on ocean discharge, but felt that the probability could be raised to 10% by research studies on the effects of

TABLE 4.13-1

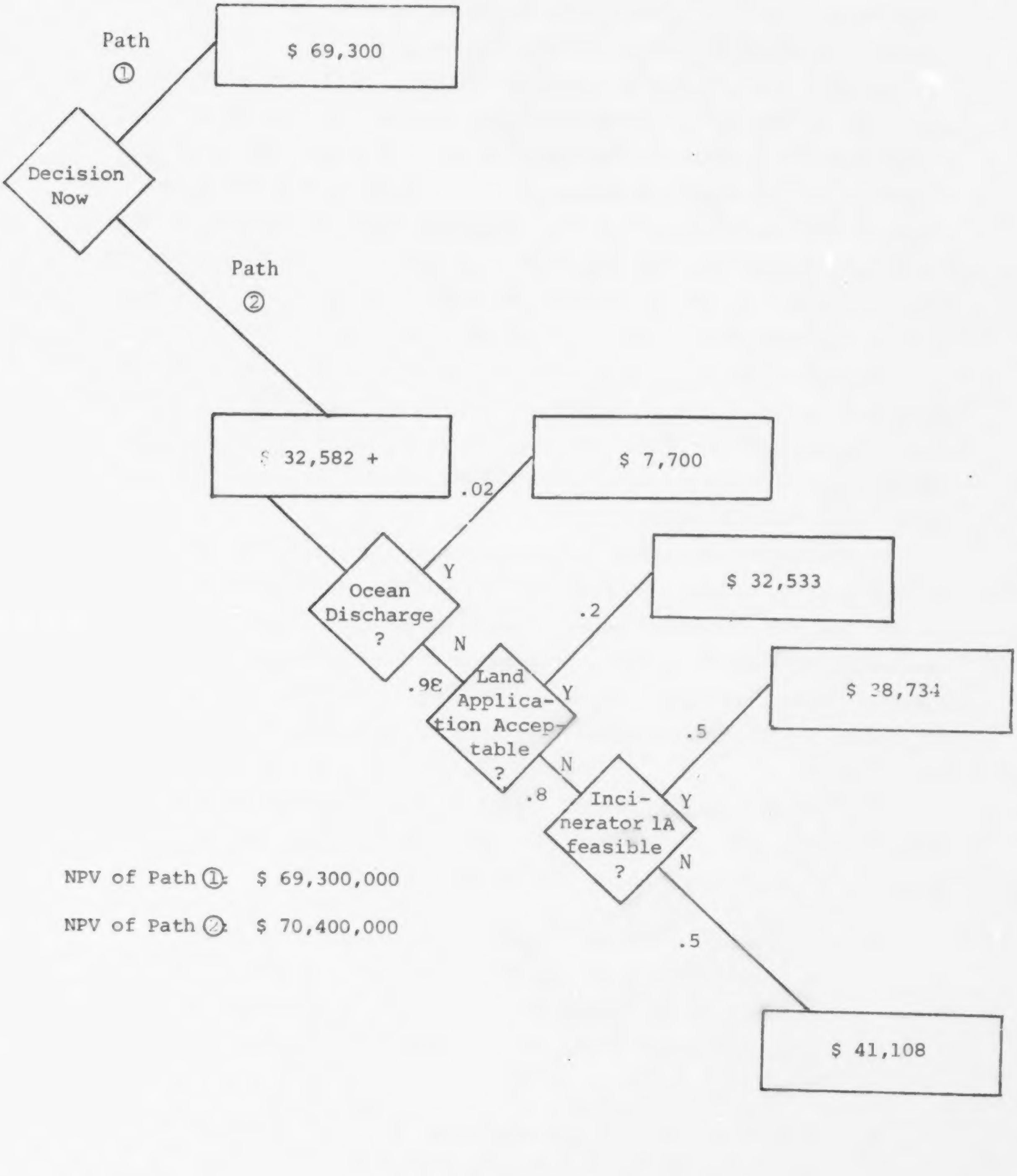
COST OF POTENTIAL PLANS

	Net Present Value: ($ million @ ENR 2200 now)
Option 1: Construct an Incinerator Now	$ 69,300
Option 2: Delay	
Landfill (7B) for five years	$ 32,582
plus	
Ocean Discharge (4A) if available	$ 7,700
or	
Land Application (9B) if available	$ 32,533
or	
Incineration (1A) if feasible	$ 38,734
or	
Incineration (1A to 1D)	$ 41,108

TABLE 4.13-2

DECISION RULE

Ocean Disposal Acceptable?	Land Application Acceptable?	Incinerator 1A Feasible?	Option Chosen (Least Cost)	NPV of Option ($000)	NPV of Option and Five Years of 7B Landfill
Yes	Yes	Yes	4A - Ocean	7700	40282
		No	4A - Ocean	7700	40282
	No	Yes	4A - Ocean	7700	40282
		No	4A - Ocean	7700	40282
Mo	Yes	Yes	9B	32533	65115
		No	9B	32533	65115
	No	Yes	1A	38734	71316
		No	1A to 1D	41108	73690


Path
①
$ 69,300
Decision Now
Path
②
$ 32,582 +
.02
$ 7,700
Y
Ocean Discharge ?
N
.98
$ 32,533
.2
Land Application Acceptable ?
Y
N
.8
$ 28,734
.5
Incinerator 1A feasible ?
Y
N
.5
$ 41,108

NPV of Path ①: $ 69,300,000

NPV of Path ②: $ 70,400,000

Figure 4.13-3 Probabilities and Costs -- National Decision

sludge, these studies would be worth about $1.4 million in total national costs. This is, obviously, a considerable amount for research, simply because the potential savings are so large.

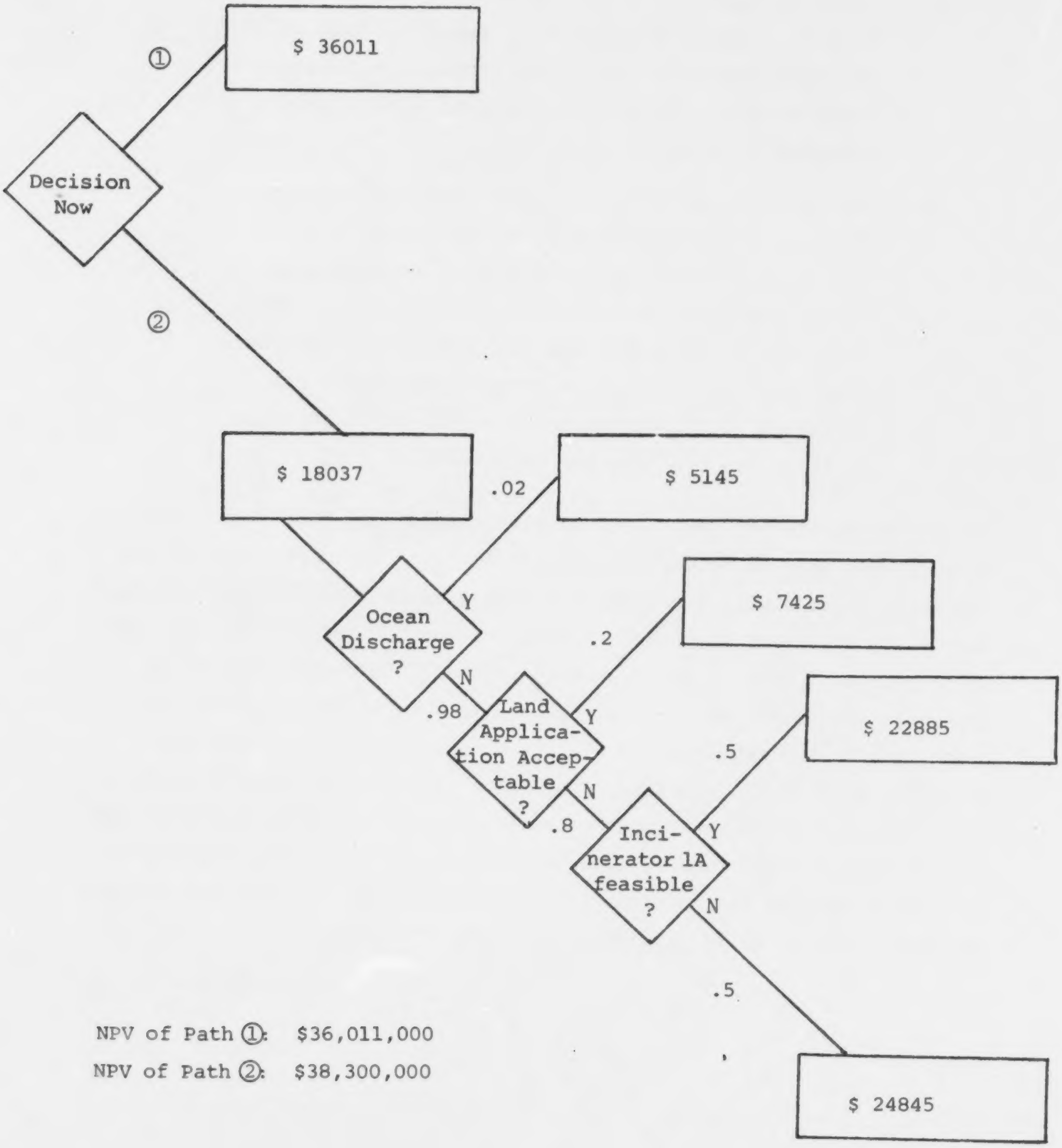
Figure 4.13-4 shows the same decision tree, this time with the direct costs to the MDC rather than the national costs. Making the same assumptions, we find that committment to an incinerator now would cost the MDC about $36.0 million (NPV), while delay would cost the agency $38.3 million (see Figure 4.13-4). From the agency's perspective, the break-even probability for ocean discharge which would make delay worthwhile would be 17%, and an increase in probability from 2% to 10% would be worth nothing to the agency in its own direct costs.

This result arises because of the Federal construction grants program, and is almost totally caused by the high O&M expenditures of landfill. In the decision tree, the Net Present Value of five years of landfill is half the NPV of a permanent incinerator solution (including replacement every 20 years).

In terms of costs alone, this discussion also makes it clear that any delay which allows continued use of ocean discharge saves the agency and the Federal government money in both the short and long runs. Since the annual cost of discharge is lower than that of any other option, and since we expect the other costs to fall in relative terms as information is gained, any delay is desirable as long as the environmental costs are not extreme.

This simple analysis shows some of the issues involved in any decision to delay, and may suggest some ways in which technical information could be of value to the decision process. For example,

- If the environmental impacts of ocean discharge cannot be convincingly demonstrated, it appears to make sense to continue the discharge of sludge. At the very least, a demonstration of "no impact" should make sludge discharge possible.
- Even if a landfill (the most expensive option) is chosen as an interim solution, a five year delay makes


$ 36011
①
Decision Now
②
$ 18037
.02
$ 5145
Y
Ocean Discharge ?
N
.98
$ 7425
.2
Land Application Acceptable ?
Y
N
.8
$ 22885
.5
Y
Incinerator 1A feasible ?
N
.5
$ 24845

NPV of Path ①: $36,011,000

NPV of Path ②: $38,300,000

Figure 4.13-4 Probability and Cost, MDC Decision

sense for national cost-effectiveness if the probability of acceptable ocean discharge is as high as 6%.* Research studies to raise the probability of acceptable ocean discharge are likely to have a benefit measured in millions of dollars.

- The decision to delay can, with reasonable assumptions, lead to significant national benefits, not only in costs but also in potential environmental impact reductions and resource conservation. The main results here are that uncertainty may have benefits, and that -- given a set of independent and uncertain sludge technologies -- it is likely that at least one will develop positively.

The conclusion is not that delay is always good, nor that strict standards always lead to better solutions. Instead, the high level of uncertainty about sludge standards and technologies makes it very possible that delay will lead to benefits, both for the MDC and for national cost-effectiveness. This is an area where technical information could be extremely useful and where a careful analysis by the MDC and EPA, unrestricted by the requirements of P.L. 95-217, could lead to better decisions both in the short and long runs. Essentially, the attempt to force implementation in advance of technology has led to problems in the current sludge incinerators, land application facilities, and so forth, and Boston and the nation might benefit from a more rational approach to implementation of these expensive and risky facilities.

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*From the MDC's perspective, a 17% probability would be required to make the extra costs of delay worthwhile, again assuming landfill in the interim.

4.14 References

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5. THE EFFECTS OF GOVERNMENTAL POLICIES ON SLUDGE MANAGEMENT PLANNING

This study has proceeded from a description of the service area and the specific conditions influencing sludge management planning in the Boston Metropolitan Area in Section 1, to an identification of the key technical issues associated with each of the three classes of sludge disposal options in Section 2. The major technical uncertainties of each disposal option were quantitatively and qualitatively described. In Section 3 a set of alternative primary sludge management options for the Boston Metropolitan Area, reflecting a range of technical and regulatory uncertainties currently facing local planners, was evaluated. Detailed cost and environmental analyses were performed for nine basic disposal alternatives under a range of technical and federal policy constraints. Section 4 examined the sensitivity of the options after removal of a number of constraints and posed a set of potential changes in three conditions: costs and prices, technologies and standards.

Section 5 discusses the influence that several levels of governmental policies have on sludge management planning on the local level. Those aspects of this report that have national significance are also presented. Section 5.1 examines MDC's efforts in the area of sludge management planning. Section 5.2 examines the state's role and Section 5.3, the Regional EPA's role. The influence of federal policy is presented in Section 5.4, while the study team's recommendations on improving sludge management planning at both local and national levels are presented in Section 5.5.

The MDC is considered to be the local government. The state government is represented by a number of agencies, the most prominent of which is the Massachusetts Department of Environmental Quality Engineering. The federal government, in this study, is represented by EPA policymakers in Washington, EPA's research centers and the regional office of EPA. For each of the three governmental levels, the relationship between the stated responsibilities and goals of the relevant agency is examined. The study team's perception of how effectively these goals are being or will be achieved is also examined. In some instances, possible reasons are provided for why specific goals have not been achieved, and lastly, improvements in sludge management decision-making are recommended.

5.1 The Metropolitan District Commission

5.1.1 Introduction

The MDC is responsible for the expenditure of federal funds for the treatment and disposal of sludge in the study area. As such, it is responsible for planning and designing, constructing, operating and maintaining all publicly-owned sludge treatment and disposal facilities.

This section examines the major MDC activities relating to sludge management planning, including operation of present day facilities, planning for future facilities, research and development activities and efforts in the area of industrial wastewater management.

5.1.2 General Organization

The three divisions of the MDC directly concerned with sludge matters are the Sewerage, Environmental Planning and Environmental Quality Divisions. Sludge planning activities occur within the Environmental Planning Division under the direction of L. Blank (formerly headed by M. Weiss).

Environmental Planning

The environmental planning division consists of several staff members. With a limited staff, it is not surprising that the majority of sludge management planning work has been contracted to consulting engineering firms. The principal work has been performed by the firm of Havens and Emerson Ltd. and has consisted of a preliminary engineering report titled "A Plan for Sludge Management" (H&E 1973) and an environmental assessment titled "Environmental Assessment Statement for a Plan for Sludge Management" (H&E 1974). When requested by Region I EPA, MDC also hired the firm of Stone and Webster Engineering to perform a feasibility study on coincineration (Stone and Webster 1976).

Environmental Quality

The Environmental Quality Division, under A. Ferullo appears to be playing an increasing role in the area of demonstration projects concerning water quality improvement and sludge treatment methods. This division has, in particular, sponsored the only MDC sludge-related demonstration project to date, namely, the composting study previously mentioned.

Sewerage Division

The Sewerage Division houses a staff of 553 including approximately 40 engineers, scientists and managerial professionals (Fisichelli 1977). The major present-day sludge-related function of the sewerage division is the operation and maintenance of the primary sludge treatment facilities, which includes anaerobic digesters. The sewerage division also maintains analytical wastewater laboratories at both the Deer and Nut Island facilities. The Deer Island laboratory, in particular, collects a large number of wastewater samples and performs a wide range of sludge analysis (see Section 2.2.2). The Division also directs a program for management of industrial wastes which includes development of sewer use ordinances and industrial waste surveys.

At the present time, the MDC does not have specific in-house expertise needed to implement either the incineration or the land application options and would hire personnel with the needed expertise when a sludge disposal option is finally chosen (Fisichelli 1977).

5.1.3 Research and Development Activities

Except for the composting demonstration study, the MDC has sponsored no substantive studies on sludge treatment and disposal over the last eight years. In particular, no in-depth studies have been performed on the possible impacts of their present method of sludge (ocean discharge) on the marine environment. The MDC's lack of effort to document marine impacts is particularly noteworthy since the available, although limited data shows little if any impacts. Given the abundant physical and biological oceanographic capabilities present in the Boston Metropolitan Area (for example, Woods Hole Oceanographic Institute, New England Aquarium and many universities and private firms), such documentation could have readily been obtained and used by the MDC to develop its case for an environmentally acceptable method of ocean discharge. This information would serve one major purpose. It would establish a benchmark or baseline condition with which future conditions of the marine environment could be compared. Such research would ensure a direct connection between scientific and engineering activities.

The MDC has contracted with Energy Resources Company, Inc. (ERCO) of Cambridge to perform a composting feasibility study, which is in progress. This study also includes a marketing analysis for the potential sale and disposal of Deer and Nut Island sludges and represents the first demonstration program ever sponsored by the MDC in the area of sludge management planning. Note, however, that the ERCO study could not have influenced the selection of options for primary or secondary sludge disposal if the sludge planning process had not been delayed by EPA. In the event of a continued delay, the results of the feasibility study may indeed influence the planning process.

The general lack of research and development activities suggests that the MDC planners have never considered exploring technically innovative options an important activity. This attitude can be contrasted with another sewerage agency, the Metropolitan Sewer District of Greater Chicago, Chicago's MSD has a professional staff of in-house sludge management experts who are employed in projects ranging from small-scale compost studies (conducted at their 4 mgd Hanover Park Plant) to full-scale studies available:

- Nu-earth program made available 199,531 cubic yards of air-dried sludge to interested users in 1976.
- Fulton County centralized land farming program used over 58,455 tons of sludge in 1977.
- A total of 52,567 tons of heat-dried sludge was used in orchards in 1976.
- A total of 120,000 cubic yards of 28% solid compost sludge was distributed by truck to users in 1976.

From this array of activities,Chicago's MSD appears to have a major interest in exploring sludge disposal options. In contrast, the MDC appears to have consistently maintained a single option approach for sludge disposal. This "limited" approach was understandable as long as ocean disposal was a viable option.

The lack of serious efforts by the MDC to explore land disposal options is apparently caused by its planners and their perception of the urgency of the issue. This lack of innovation may also be, to some extent, influenced by the procedures the agency must perform to procure funds for performing innovative studies. A brief review of the consitution or the enabling legislation of the MDC provides insight into the manner in which this agency procures such funds.

5.1.4 Historical Role of the MDC

Historically, the MDC has been a multipurpose public utility, one of whose responsibilities was to construct, operate and maintain a system of wastewater treatment and disposal for the City of Boston and over forty municipalities in the Greater Boston Metropolitan Area, as well as to operate and maintain a water supply, parks and road system. Until recently, the MDC was a separate agency of state government, but was never an "authority" and has always lacked the independent fiscal powers that typically characterize metropolitan sewerage authorities in other states.

The MDC has traditionally functioned as a wholesaler of sewer (and water) services to its member municipalities. Control over industrial sewer connections to tributary municipal systems, including enforcement of the MDC's own sewer ordinance, was left largely to the municipalities themselves and to the Division of Water Pollution Control. The MDC has preferred to pressure (not always successfully), member municipalities to regulate the volume and character of wastes introduced into the metropolitan system through sewer connections. Moreover, since only primary treatment was offered at the MDC's central facilities, the MDC did not need to develop or insist on any compliance with its sewer use ordinance.

As already noted, the State Legislature has never vested the MDC with independent fiscal powers. The MDC cannot float a revenue bond, nor any kind of bond, without express authorization of the Legislature. Local shares of the MDC's construction and operating costs are allocated among the member municipalities, which remit their payments, not to the MDC, but to the State Treasury, from which all monies advanced for purposes of the MDC must be separately appropriated by the Legislature. In short, the MDC is an umbrella utility, designed for the convenience of its municipal members, and their political support has always been indispensable to whatever projects or programs the MDC might propose.

By the reorganization of environmental functions in 1972, the MDC became one of five major departments within the Executive Office of Environmental Affairs (EOEA). With the approval of the Governor, the Secretary of EOEA appoints the Commissioner and Associate Commissioners of the MDC. This reorganization does not greatly alter the MDC, but may serve to bring it into closer contact with other agencies of EOEA, particularly the Departments of Environmental Quality Engineering, Environmental Management and Food and Agriculture.

5.1.5 Pretreatment of Industrial Wastes in the Metropolitan Sewerage District

The presence of heavy metals in MDC's sludges has been identified as a factor that influences all disposal options. For example, the metal content of sludge is important to any consideration of ocean dumping, land application and composting; moderately important for landfilling, and important, though still significant, for incineration followed by ash disposal in landfill. Therefore, if the MDC wished to maximize its sludge disposal options, it would direct its efforts towards reducing the metal and other toxicant content of its sludges. Since attempting to remove metals from the sludge at the treatment plant is not practicable, pretreatment by industrial users of the MDC system will be necessary.

The impetus for pretreatment arises from two other considerations. The first applies specifically to the MDC and is related to its NPDES permit. The second is more general and relates to federal pretreatment activities.

The NPDES Permit

Under PL 92-500, the EPA and the State Division of Water Pollution Control jointly issued a discharge permit on April 2, 1975 to the MDC. The permit covered the discharge of conventional pollutants such as BOD_5 and suspended solids. The permit contained no effluent limitations for metals or for other particularly industrial wastes, but left the possibility open for later amendments specifying such limitations.

As originally issued, the permit required the MDC to have in effect by September 1, 1976 both a system-wide set of sewer use regulations and an acceptable program for implementing and enforcing them.* Such regulations were to prohibit introducing into the system any "toxic pollutant in toxic amounts," any pollutants that would interfere with the treatment works and any "incompatible" pollutant in amounts or concentrations exceeding applicable federal guidelines. An "incompatible pollutant" was defined in the permit as any pollutant, other than those for which effluent limits are specified, "which the treatment works was not designed to treat and does not remove to a substantial degree." A catchall provision prohibiting introduction of any pollutant that "has not been subjected to any pretreatment that may be required under Federal or State law" would be promulgated.

To conform to the permit, the MDC's regulations had to require industrial users to notify the MDC of proposed changes in or additions to their wastewater flows; to observe self-monitoring (including record-keeping and reporting) procedures and to submit to inspection of their premises by the MDC for compliance with the foregoing requirements. Finally, the permit obliged the MDC to submit to EPA semi-annual reports of progress toward compliance and prescribed deadlines for the MDC to establish an industrial waste section and complete a survey of all major contributing industries.

Federal Pretreatment Requirements

Quantitative Federal Pretreatment Standards for the electroplating industry (considered to represent the major source of metals in the Boston area) were promulgated in interim form by the EPA in July 1977, but apply only to cyanide, hexavalent chromium and pH. Further electroplating pretreatment standards are expected in the future and will cover additional heavy metals.

Not only has the issuance of final federal pretreatment standards been delayed for several years, but now a major change in EPA's pretreatment strategy appears to be occurring. As a result of numerous public hearings, in which several different strategies for regulating pollutants discharged to minicipal treatment works were discussed, a new strategy is being adopted by the EPA. Based on preliminary information, the new strategy differs significantly from the earlier approach (Hare 1978). Some of these differences are noted below.

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*MDC's newer and current permit was issued in August 1976 and is discussed in a later section.

- The notion of regulating "incompatible pollutants" is replaced with "toxic pollutants." The toxic pollutants that will be regulated are those contained in the "Consent Decree" List of 65 toxicants and toxicant classes.
- Standards for these chemicals will be in terms of concentration units, and the removal technology will be similar to best available technology economically achievable.
- The National technology-based standards for toxic pollutants may be modified by the owner of the municipal treatment works to reflect the degree of reduction of that pollutant achieved by the treatment works. That is, a local credit will be given to the industrial discharges.
- EPA will subsidize 75% of the development costs of an industrial waste management program, including the industrial waste survey and in particular the necessary monitoring program.

Existing Sewer Use Regulations

On paper, the MDC has had in effect for a number of years a set of regulations on the introduction of industrial wastes into tributary sewers. These regulations not only prohibit municipalities, in general terms, from introducing any toxic, hazardous or incompatible wastes, but also expressly provide that "[a] 11 wastes containing toxic heavy metals must be treated for removal of these metals to values at least equivalent to the minimum solubility of their oxides or hydroxides. Limits for non-metals must be reviewed and approved separately."* Further clauses prohibit dilution by extraneous or other nonprocess water in lieu of treatment as a means of attaining required levels of discharge and prohibit direct disposal of concentrated plating solutions. "A description of the proposed treatment system, including flows of all waste drains and concentrations of toxic or objectionable metals or non-metals before and after treatment must be submitted to the MDC for approval."* These specific requirements are addressed directly to industrial users and are characterized as "clarification . . . intended to assist industries . . . in interpreting" the more general prohibitions addressed to municipalities.

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*St. 1974, c. 806, SS7, 8.

The authority exercised by the MDC in promulgating its sewer use regulations appears to have been supplied by two statutory sources. The first is an Act of 1945 that authorized MDC "to adopt . . . rules and regulations concerning the discharge of . . . wastes into any sewer under its control, or any sewer tributary thereto . . ." (MDC 1974) By the terms of the 1945 Act, the MDC can enforce such regulations only against a noncomplying "municipality," but it is arguable that they may be addressed in the first instance both to municipalities and to industrial users who discharge into tributary sewers and be enforced under separate statutory authority against industrial users by the Division of Environmental Protection within the Attorney General's office. The second source of authority is the general law, governing sewers and drains, which includes a provision empowering any "district" to "prescribe rules and regulations regarding the use of common sewers to prevent the entrance or discharge therein of any substance which may tend to interfere with the flow of sewage or the proper operation of the sewerage system and the treatment and disposal works . . . !and1 . . . for the construction, operation, and use of all connections entering into such sewers . . ."** Though the point is not beyond dispute, the MDC could be fairly characterized as a "sewer district" for purposes of this provision.

However, the MDC to date has done little to implement and enforce the pretreatment standards set forth in its regulations. There are several reasons for this relative absence of enforcement activity.

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*28 M.G.L. S1, as amended by St. 1975, c. 706. S81.

**St. 1945, Ch. 705, S12.

First, administration of the "minimum solubility" standard for toxic heavy metals and review of plans for pretreatment systems call for case-by-case determination through a permit system that would apply to all subject users, but at least until recently, the MDC was not provided with the necessary technical or economic resources to identify the many industrial users of tributary sewers, much less run a significant number of them through the administrative procedures of a permit system. Second, the MDC was not convinced that it could lawfully address regulations directly to industrial users, and it may have been reluctant to provoke economically marginal firms into mounting a legal challenge to its authority, or into closing down or moving out of state under enforcement pressure. Finally, the vagueness of the water quality standards concerning industrial components in the MDC's discharges to Boston Harbor, combined with the presence of only a primary treatment process for the metropolitan system, gave the MDC practically no incentive to crack down on industrial users. It did succeed in getting some users to pretreat their wastes. For the most part, however, users of relatively long standing (as distinguished from new users, who have had to obtain connection permits from the Division of Water Pollution Control) are not pretreating their wastes and have not yet been ordered to do so.

New Law to Strengthen the MDC

Partly in response to pressures generated by the NPDES, the State Legislature enacted a new law (Acts of 1974, Ch. 814)* expressly authorizing the MDC to

> "require present and prospective municipal, industrial, or other users of the metropolitan system, or of any sewer tributary thereto, to comply with applicable provisions of federal or state law respecting (1) toxic and pretreatment standards; (2) construction, operation, and maintenance of pretreatment facilities; (3) monitoring, record-keeping and reporting of discharges to the system; [and] (4) notification of proposed new discharges to the system . . ."

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*Acts of 1975, Ch. 814, enacted on December 22, 1975, and codified as 92 M.G.L. SS1A-9. This law was also prompted by the need to revise the formulae for sharing costs of the MDC, in order to qualify it for construction grants under S204 of PL92-500.

The Act also authorizes MDC to perform compliance inspections on any premises connected to the metropolitan system; adopt regulations for implementing and administering its new statutory powers; and issue administrative enforcement orders against violators or refer them to the Attorney General for judicial assessment of civil or criminal fines ranging from $1,000 to $10,000 for each day of violation. These provisions dispel all previous doubts about the ability of the MDC to assert direct regulatory power over industrial users of the metropolitan system (though such an assertion still has to reflect other, "applicable" provisions of federal or state law). At the same time, recognizing the continuous importance of the municipalities within the district, the Act provided that

> "each city or town served by the metropolitan system shall have in effect a sewer-use ordinance no less stringent than regulations of the Metropolitan District Commission itself pertaining to dewer use, together with procedures for monitoring and enforcing compliance with such ordinances . . . Sewer use or ordinances and regulations shall be subject to approval by said commission."

Proposed New Regulations

Spurred on by the requirements of its NPDES permit and by the fresh authorization it had received from the Legislature, the MDC, in 1976, proposed new regulations concerning discharges of industrial (and other) wastes to sewerage works within the metropolitan district.* Under the proposed regulatory scheme, every member municipality would have to obtain a permit from the MDC covering all municipal connections to the metropolitan system and every user discharging industrial waste directly into that system would have to obtain a permit to be jointly issued by the MDC and by the host municipality. This dual permit system reflects a new political balance between the MDC and its member municipalities.

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*The original permit, dated April 2, 1975, was subsequently revoked and replaced by the permit issued in August 1976 under which MDC is now operating. Compliance with the permit was assured with the inclusion of timetables in the Enforcement Compliance Schedule Letter (ECSL) issued at the same time.

As envisaged in the proposed sewer use regulations, the wholesale permit issued by the MDC to each municipality may contain limits on constituents and volumes of discharges; specifications for monitoring equipment and procedures; a schedule for enacting or amending the municipal sewer use ordinance required by law and a schedule for completing an industrial waste survey within the municipality. The permit jointly issued by the MDC and the municipality to every industrial user may specify effluent limitations, pretreatment requirements, monitoring procedures, reporting schedules and implementation schedules. For both types of permit, a catchall provision will enable MDC to add "other conditions . . . deemed appropriate by the Commission to ensure compliance with . . . state or federal law."

The highly unusual provision for joint permitting of industrial users assumes that the MDC and the host municipality will agree on the terms that industries must observe despite the well-known reluctance of many Massachusetts municipalities to enforce costly pretreatment requirements against industries on whom the local tax base heavily depends. In any conflict with a municipality on this subject, however, the MDC would have the upper hand, first, because of the supremacy of state and federal law with respect to pretreatment and, second, because of the MDC's authority to take enforcement action against any user who fails to meet the requirements of law. In other words, an industrial user must convince not only his municipality, but also the MDC itself to ussue a permit, and if there is any discrepancy between the terms on which the respective co-permitting authorities would issue it, the stricter set of requirements would be bound to prevail.

In addition to prohibiting introduction of any waste that would be harmful to or incompatible with the treatment process and any waste that would adversely affect receiving waters or endanger life, the MDC's proposed regulations would prohibit introduction of wastes containing designated toxic or objectionable substances, including both metals and nonmetals "in excess of the concentrations attainable by acceptable control technology . . . ." In general, wastes containing any of the seventeen designated metals (including cadmium and chromium) must accordingly be treated "to reduce their concentrations to the minimum levels attainable by chemical precipitation processes." Final sewer use regulations have not yet been issued.

5.1.6 Summary of MDC's Sludge Management Planning

- The impact of EPA's final pretreatment standards is uncertain. The MDC has proposed its own industrial sewer use regulations. Finalization and implementation of the regulations is influenced by the Legislature as is the need for further staffing to monitor the industries and complete an industrial waste survey.
- Although the MDC has a small planning group, they have made substantial use of outside consultants to meet their needs.
- Because of the dependence of the MDC on the Legislature, it would be difficult for the MDC to implement a land application facility, especially if land outside their service area were necessary. If the land option could not be implemented, the MDC might not meet the EPA's grant elegibility requirements.
- The MDC is in an advantageous position to implement the composting option since it has access to MDC parklands and potential access to parklands of its member communities.
- The incineration option could be implemented, but the MDC would be vulnerable to legislative pressures that could result in the shutdown of a newly constructed incinerator.
- The MDC has only a limited program for performing research and development on methods for treating and disposing of sludge or measuring its impacts on the marine environment.

5.2 State Government

5.2.1 Introduction

Although the role of state agencies in sludge management planning in the study area has been small compared to that of the MDC and Region I EPA, it has nevertheless influenced events. Under the states' influence, the activities of the following agencies will be considered:

- Executive Office of Environmental Affairs,
- Department of Environmental Quality Engineering,
- Department of Food and Agriculture,
- Department of Environmental Management and
- Legislature-Organic Waste Recycling Commission.

5.2.2 Executive Office of Environmental Affairs (EOEA)

In 1972, a reorganization of environmental functions in the state led to the creation of EOEA, which has five major departments. These departments include the MDC, Environmental Quality Engineering, Environmental Management, Food and Agriculture, and Fishery and Wildlife. As a result of this particular clustering of departments under EOEA, the Secretary of Environmental Affairs is potentially in a key position to influence state environmental policies affecting sludge management. The potential coordination of activities and interaction between the MDC and Food and Agriculture is particularly relevent with respect to agricultural uses of wastewater sludges.

5.2.3 Department of Environmental Quality Engineering

The Department of Environmental Quality Engineering (DEQE) has the regulatory responsibility to establish standards of performance for both landfills and for land application facilities in the state. The sludge disposal option for which DEQE has the greatest potential influence in the study area is land application. A very preliminary state policy has been developed and is set forth in a letter (Appendix 5A) from Commissioner Standley. The letter reflects a cautious or conservative policy toward land application with approval for application mode given on a case-by-case basis. Although the letter contains the basic elements of a state policy for landspreading of dewatered or composted sludge, detailed guidelines, such as those existing in more than 30 states, are lacking. For example, loading rates based on nitrogen or metals are not described, nor are methods of stabilization described in any technical detail.

The absence of detailed guidance is viewed as one major reason why the landspreading of sludge is not widely performed (Colby 1978). Standley's letter establishes that the decision process is conducted on a case-by-case basis. This manner of procedure probably serves to discourage prospective users of the landspreading option.

However preliminary, the policy is an improvement over the form of guidance presented by EcolSciences in the Draft EIS in which a personal communication from Mr. Anderson of DEQE was the sole basis for a decision to pasteurize sludge that had already received anaerobic digestion (therefore contributing a significant cost to land application). In general, however, it appears that DEQE and its minimal guidance provided in the DEQE letter do not represent an obstacle to the increased use of land application.

5.2.4 Department of Food and Agriculture

The Department of Food and Agriculture (DFA) could have a significant role as a participant in programs involving the application of sludges on agricultural soils. Although the Department has no regulatory authority in this area, it does have a well publicized goal to reverse the disastrous rate of decline of agriculture in the Commonwealth (Boston Globe 1975). Using federal monies for the application of wastewater sludges to agricultural soils represents one means of subsidizing agriculture in the Commonwealth. The mechanism for accomplishing this is found in the EPA's construction grants rules, which allow the federal share of wastewater facilities (75% of capital expenditure) to include the purchase of land and farming machinery. In addition to the outright purchase of land, the funding rules would permit a flexible range of options from direct ownership to leasing arrangements. However, in order for a shift in funding from the more conventional wastewater treatment facilities such as incinerators to nonconventional facilities such as land application facilities to occur, active participation in sludge planning by the DFA would be required.

Because both the DFA and the MDC are within the EOEA, significant support would be possible for greater future cooperation between the two departments. (See Appendix 5B for further elaboration of this notion.) Although the DFA has participated in the Commission on Organic Waste Recycling, it has not attempted to influence the MDC's sludge management planning process in an active fashion.

5.2.5 Department of Environmental Management

The Bureau of Solid Waste Disposal within the Department of Environmental Management (DEM) has the major state responsibility for providing planning and technical assistance to cities and towns on the treatment and disposal of sludge. This responsibility largely is the result of the EPA's inclusion of the term sludge as a type of solid waste. The Bureau does not now have the budget or staff to act as the prime focus for sludge planning in the state (Hauser 1978). The Bureau mostly assists cities and towns outside of the MSD, and it has not played a role in sludge management planning in the study area.

5.2.6 Legislature

In 1976, a bill (Senate Bill 1963) was brought before the Massachusetts Senate to establish a Commission on Organic Waste Recycling. The Commission was to be charged with investigating the potential for the use of municipal sewage on agricultural land. The legislation creating the Commission failed to pass that session of the legislature. The Secretary of the Executive Office of Environmental Affairs, Evelyn Murphy, then decided to establish the Commission from her Office. This was done, and membership was appointed in January 1976.

The Commission received support and pledges of commitment from such agencies and units as the MDC, DFA, EPA, University of Massachusetts and a number of other interested segments of government. Secretary Murphy chaired the Commission, Vice Chairman was Commissioner of Agriculture

Frederic Winthrop, and Cleve Willis of University of Massachusetts was Executive Director. Other members included MDC Commissioner Snedeker, Environmental Quality Engineering Commissioner Standley and Representative Mel King.

In brief, the Commission was established to study and recommend possible economically and environmentally sound alternatives to the traditional methods of disposal of sludges and other wastes. These alternatives primarily fall into two categories: application to agricultural or forest land by some means of spreading or injection and composting by a variety of techniques.

The basic work of the Commission was accomplished by two task forces on land application of sludge and composting of organic materials. The Commission was also responsible for extending the task force findings and results to the Commonwealth's situation. The task forces submitted their reports to Secretary Murphy in April 1977. The Secretary accepted the reports in January 1978; public release is expected soon. The approved reports will be submitted to the Commissioners of each department of the EOEA. Regulations will then be produced in accordance with the recommendations of the reports.

5.2.7 Summary of State Sludge Management Planning

- The major departments in state government dealing with sludge management planning are all part of EOEA. This arrangement should encourage interaction and coordination of sludge policies. However the study team was unable to find any evidence of coordination between the individual departments.
- Within the state, no individual or group is responsible for all aspects of sludge management planning. The Bureau of Solid Waste Disposal within the DEM comes closest to performing this role, although it has not extended its activities to include the Metropolitan Sewerage District and the Deer and Nut Island treatment facilities in particular.
- The 15,000 acres of disturbed land identified by the study team as potentially suitable for reclamation by the use of sludge should be evaluated in further detail by the Bureau of Solid Waste Disposal.

5.3 Region I EPA

5.3.1 Introduction

Region I EPA is responsible for issuing (jointly with Massachusetts DWPC) the NPDES permit to the MDC for its wastewater facilities. In addition, Region I determines the degree to which the MDC must comply with construction grants eligibility requirements and is responsible for approving any federal funding to the MDC. The agency is also responsible for ensuring that National Environmental Policy Act (NEPA) requirements are satisfied.

5.3.2 Research and Development

Region I has been most active in the area of EIS work for sludge planning and management. However, it has been nearly totally inactive in the area of research and development, having neither participated in nor sponsored any sludge treatment and disposal projects on either a research or demonstration level in the study area.

Neither EPA Region I nor EPA's Narragansett Research Laboratory has sponsored marine studies on the effects of sludge discharged to Boston Harbor. While over the last eight years scientific and engineering studies not directly focused on sludge have been conducted (and also are presently under way) in Boston Harbor, no effort appears to have been made by EPA to coordinate such basic studies with ongoing sludge management plannning.

5.3.3 EIS Activities

The major sludge-related activities of Region I were initiated in response to the MDC study entitled "A Plan for Sludge Management." This study, prepared for the MDC in 1973 by Havens and Emerson, as well as a second Havens and Emerson study entitled "Environmental Assessment Statement for a Plan for Sludge Management," was presented to Region I in 1974 for review and comment. These studies recommended the incineration option. At that time the MDC studies were not formally part of an MDC grant application review (Weiss 1977).

EPA Region I informally rejected the MDC sludge plan and hired EcolSciences, Inc. in June of 1975 to prepare an EIS on its own version of a sludge management plan. This action was somewhat unusual since EPA, if acting in accord with NEPA, should have formally accepted or rejected MDC's plan and assessment. If EPA rejected the MDC plan, the MDC would have been required to submit a new plan. In other words, the "Plan" should be the prerogative of the local sewerage agency, namely, the MDC. This departure from the more conventional EIS process was reportedly (Shaughnessy 1977) initiated because EPA felt that the MDC had not fairly considered all possible options and would probably resubmit a plan with similar deficiencies.

The EcolSciences' Draft EIS was approved by Region I in February 1976. It recommended, as did the H&E Study, the incineration option. In October 1976, Stone and Webster Engineering completed a study of a coincineration alternative for the MDC. This later study was performed in response to comments on the draft EIS.

EPA's sludge management plan differed substantially from the MDC's in two ways. Most signficantly, it separated sludge planning into distinct primary and secondary phases and dealt exclusively with only the primary sludge phase with a design year projection of 1985. (The MDC's design year was 1995 and included secondary sludge planning.) By separating primary sludge from secondary, the EPA, in effect, left the option open for selecting and implementating a different option for secondary sludge disposal. The EPA's primary sludge plan also differed from the MDC's by requiring that the incinerator ash be landfilled at a remote site rather than at Deer Island. Neither the EPA nor the MDC plans considered sludge composting and utilization as an option.

5.3.4 Summary

- EPA usurped MDC's position as primary planner of sludge disposal facilities in Boston. Such action is not in accord with NEPA and was begun even before the MDC submitted a grant application for a sludge disposal project.

- Region I's sludge management plan was more flexible than the MDC's, as it planned for the disposal of primary sludge only, thereby keeping an "open mind" on disposal of secondary sludge.
- In keeping its options open for secondary sludge disposal, EPA concluded that secondary sludge would be less contaminated with metals and would therefore be more amenable to soil application. The study team has found no basis in fact for that conclusion. It is even possible that secondary sludge would have a higher metal content than primary sludges.
- The EPA, in recommending advanced incineration technology for primary sludge, did not acknowledge the technical uncertainty of this incineration option.
- Although EPA considered heat dried sludge for use as a fertilizer, it did not consider composted sludge.
- Although this study has shown that an MDC-run land application facility could be cost effective (in contrast to EPA's version of the landfarming option), the study team recognizes that the MDC would have serious difficulties in implementing the option because of the probable impeding influence of the legislature. Since the study team has argued previously that the MDC is not able to fairly consider an otherwise cost-effective option, the EPA should have considered the MDC's institutional arrangement as possibly in violation of the EPA's grant eligibility requirement.
- The EPA has delayed the MDC sludge effort by rejecting the MDC sludge plan and maintaining its plan in draft form at least until February 1978. In so doing, another option, composting, has been shown in this study to be cost effective, and also in the interim the MDC has initiated a demonstration study.

5.4 Federal Policy Conclusions and Recommendations

In addition to the federal rules that address the treatment and disposal of sludge, Section 301 of PL92-500 has an overriding influence on sludge management planning because it mandates an increase in sludge production by requiring primary treatment plants, such as the MDC's Deer and Nut Island facilities, tc be upgraded to secondary treatment.

Federal policies act as significant constraints on the solutions that can be considered for sludge management at the local level, but they also provide much of the incentive for finding solutions. Without the discharge requirements of PL92-500, for example, sludge discharge to the ocean would appear to the local government to be a satisfactory disposal option. Without the constraints of the Clean Air Act, and the operational aspects shown in State Implementation Plans, effective pollution controls on incinerators would be much less evident. The federal government has taken the role of providing incentives and defining constraints on local actions, so its policies have a major impact on local planning processes for sludge management. Several of these policies and their local impact are described below.

Grant Eligibility

No physical difference exists between a co-combustion incinerator owned and operated by the MDC and the same incinerator owned and operated by a private firm. Each would accept about 120 dry tons/day of primary sludge and about 1,500 tons/day of solid waste from the area. Yet one would be eligible for a construction grant as a publicly-owned treatment works, while the other would not. In the latter case, the total cost to the MDC would be the same, but it would be largely an O&M cost, not subject to grants. The same problems exist with sludge landfills, barges and other portions of the system where it might be more efficient for the MDC to deal with private operators, but would also be more expensive to the local taxpayer.

This problem with the construction grants process is well-recognized and is demonstrated in Boston as well as in other areas. The reverse issue -- industrial discharge using municipal plants -- has been the subject of Industrial Cost Recovery requirements, leading to subcharges or, under the new amendments to PL 92-500, to ad valore tax payments by the industries for their share of costs. A similar structure, allowing the municipality to contribute capital for a portion of a private facility under the grants program in return for partial ownership, would appear reasonable and could be an improvement on the current program. Otherwise, local agencies will be encouraged to vertically integrate to maximize grants, even if this procedure, from the national perspective, wastes money.

New Technologies

The 1977 Amendments to PL 92-500 (The Clean Water Act of 1977) are full of suggestions for ways to use new technologies and ways in which these technologies can be supported (increased grant funding, lowered cost-effectiveness requirements and a clearinghouse for information). This study's review of the available information on the "new generation" of sludge incinerators, reveals that more information on the performance of both the new and old technologies is required. The Boston Case Study illustrates the need for such information. In this study an advanced design form of incineration is the currently recommended option and is the choice of both the local planning agency (MDC) as well as Region I EPA. This technology choice has been made on the basis of extremely limited national experience. Significantly, six or fewer of these incinerators have been constructed and are currently operating in the United States (as of October 1977). Of these six, none, or perhaps only one, have operated continuously and in an autogenous mode at design specification for six months or more.

Incineration is both the local choice and, apparently, a popular national choice since approximately 40 advanced design incinerators at various stages of design and construction exist. In this situation the role of a clearinghouse for information (Section 7) is an extremely important one. This clearinghouse should particularly attempt to gather operations data since these data are notoriously difficult to find on the local scale. The clearinghouse should not only gather information on those technologies defined in some regulatory list, but also should be free to include significant technology variations that might not qualify for the extra percentage grant, but would be additional options to consider. With the rate of change of sludge management technologies, the EPA must keep track of the success or failure of large-scale systems, and the clearinghouse appears to be the most appropriate body to perform this function.

Pretreatment

PL 92-500 calls for pretreatment by industries to remove components that are not susceptible to treatment or that might 'upset' treatment works; EPA's guidelines have been concerned with defining which pollutants are compatible with treatment and which are not. The Clean Water Act of 1977 amends Section 307(b) of PL 92-500 and makes contamination of sludge one of the criteria for pretreatment standards. The recent amendments (Section 54) do not require pretreatment of toxics if the effluent limits are not exceeded for the toxic pollutant, and sludge disposal is not prevented. However, the new amendments also allow EPA to intervene in the enforcement of pretreatment standards if the local government does not expeditiously perform its own enforcement.

Pretreatment was analyzed to determine the suitability of various disposal options for sludge. Some sludge disposal technologies are relatively insensitive to pretreatment needs, particularly the combustion options. Others would benefit from pretreatment, but not to an important degree; for example pretreatment would help reduce metal loadings for ocean disposal, but not sufficiently to allow that alternative to meet EPA's present ocean disposal standards. Pretreatment would have the greatest impact on land application, where the expected federal land application criteria would recommend approximately 50% metals removal from Deer Island's sludge to make agronomic application rates feasible (without extensive monitoring programs). Pretreatment would be cost effective for secondary sludge because of the larger quantities, and would be particularly desirable for application at dispersed sites, because there would be little agency control over private use practices. For an MDC-owned facility, however, the cost of pretreatment may be equal to the cost of additional land for primary sludge use at lower application rates.*

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*Federal funding for aiding municipalities to establish an industrial waste management program was assumed to be unavailable. The new pretreatment strategy, if adopted, proposes a federal subsidy covering the municipality's cost of organizing an industrial wastewater management program.

While pretreatment may open up sludge disposal options that are not otherwise available, it should not be viewed as a free benefit. An investment in pretreatment should lead to net benefits, and the benefits are shown in the operation of the treatment plant and the disposal of effluents and sludges. If pretreatment costs lead to commensurate reductions in treatment or sludge management costs, pretreatment should be undertaken. However, pretreatment is only one part of the process and should be subject to cost-effectiveness analysis just as the other portions of the treatment and sludge management process are. Note that this cost-effectiveness comparison should be from the perspective of the public sector to be consistent with other EPA requirements. Thus, the costs to the local agency and benefits accruing to it should be considered, but not the private costs. In evaluating land application, then, neither the private costs to industry for pretreatment nor the private benefits to farms should be included in the analysis, only the tradeoff for the sewerage district should be considered.

There is no doubt that pretreatment makes land application more attractive; it is the study team's feeling, however, that if land application demands pretreatment that would otherwise be unnecessary, then the land application option should include the costs of pretreatment.

Standards for Land Application

The standards for land application of sludge have been subject to continued national delays. At present, EPA is developing criteria for land application and guidelines to implement the criteria. These items have been given a high priority in the Draft Strategy for Implementing the Resource Conservation and Recovery Act of 1976 (EPA 1977). However, these criteria have not appeared yet in final form; the currently available information is contained in the Technical Bulletin, which was itself subject to long delays before it was issued. The reasons for these delays are not of interest, only the effect of the absence of standards for land application on the Boston area is of concern. One major effect occurs: land application becomes difficult to support as an effective option when it is unknown whether a facility will be allowed to operate after standards are developed. Land application by farmers should not be implemented if the farmers are not allowed to use the sludge at a later time; the same is true for crop production at an agency-owned site, although it might be possible to continue operation under tighter control in that case. Therefore, application to food-chain crops cannot comfortably be recommended as long as the national regulatory environment is undefined.

When the standards are developed, they may have a major impact on the costs of land application. For example, cadmium limits might make pretreatment a requirement for the applied or distributed sludge or limit the application rates for sludge to less than the agronomic optimum. On the other hand, the sludge application program would be aided by rules and guidance for the operation and monitoring of a program, such as those to be developed in the land application guidelines. In the interim, the lack of land application guidelines has prevented the widespread implementation of land application in Massachusetts. This situation has not been the case in more innovative areas such as Chicago, which has been operating a land reclamation site in Fulton County for seven years.

Cost-Effectiveness

The evaluation process for systems funded under the Construction Grants Program requires that the most cost-effective and environmentally sound option be chosen. The cost-effectiveness guidelines, however, do not admit to uncertainty in costs. If a system that cost $100 with certainty were available, and another existed with an expected cost of $99 but with a significant chance of costs on the order of $1,000, the EPA would require the latter choice. In cases that are not as clear cut, but where uncertain technologies exist, the procedures will result in the choice of options with lower expected costs but higher risks. Legal uncertainties are equally difficult to consider in the analysis. The cost-effectiveness procedures should not attempt to assume that uncertainty does not exist, but allow this uncertainty in choosing individual systems to be considered explicity.

A second cost-effectiveness issue requires choosing the most cost-effective and environmentally sound option. It is clearly conceivable that EPA would find land application to be most cost-effective, while the MDC would prefer incineration (or vice versa). The national cost-effectiveness goal is important, but local issues such as site location, perceived environmental impacts, and so forth, are also significant. There seems to be no obvious reason why EPA could not set the grant amount according to the cost-effectiveness criteria, but allow the local authority to build a more expensive option, if it desired to pay the incremental costs. For example, if EPA computed the capital cost of land application at $20 million and incineration at $25 million, EPA would provide a 75% grant for the lower-cost system ($15 million), but the local government could invest $10 million instead of $5 million and build an incinerator. Computing the grant on the most cost-effective option could simplify the evaluation process and would reduce federal control over what is supposed to be a local program.

Landfill Standards

Along with the land application criteria and guidelines, EPA is developing criteria and guidelines for landfills and the use of surface impoundments. These standards will probably make landfills a less popular option than at present, though this situation will probably have little effect on the MDC. The standards may have an impact on the surrounding communities, where much of the sludge and septage are landfilled, often in unsuitable sites, and it will clearly affect many other areas. If the MDC decides to develop a landfill alternative, the criteria and guidelines would probably limit the availability of sites and increase site development costs somewhat.

Deadline Requirements

In developing pollution control policies, Congress has set a number of significant deadlines. From the sludge management perspective, the most significant deadline is the requirement for secondary treatment under best practicable technology (BPT), which was first set for July 1, 1977 and has recently been extended to July 1, 1983 for municipalities that meet certain conditions. Secondary treatment implies some acceptable means of sludge disposal, and construction delays lead to a need for fast action in choosing a technology and proceeding with design and construction. Primary sludge, of course, must be managed in an acceptable manner by that time or before.

The analysis in Section 4 suggests that delaying final selection of a sludge disposal technology beyond the 1983 date may be desirable, given current information on the technologies and the potential for change. Delay may mean more expensive (but environmentally acceptable) interim solutions. However, if delay leads to sufficient cost reductions, it may be possible to demonstrate the advantages of such a delay and build at a latter date when more information has been gained. However, this scenario is not possible under the Clean Water program; delays are not an acceptable option, and it is very difficult to revise plans in light of additional data. While this policy may have been made for administrative simplicity, it implies that investments are being made in untried technologies and systems that may fail, simply because the results are demanded immediately. It seems possible to develop an approach to delay that would require performing a careful analysis and demonstrating significant total benefits.

On a related note, the costs of wastewater treatment have been rising quickly at a faster rate than the measures of inflation for the economy as a whole. The cost-effectiveness approaches required by EPA understate the costs of future O&M in their evaluation as follows:

1) The analysis claims to be in constant dollars, so uninflated O&M amounts are used.

2) Constant capital payments are also used, based on actual bond amounts. These, however, are in constant dollars and do not change over time.

3) To perform a constant dollar analysis, the capital payments in current dollars should be deflated by the inflation rate; conversely, to perform a current dollar analysis, the O&M payments should be inflated. Either way, O&M is understated with respect to capital.

The current procedure seriously affects the choices of engineers and local governments, and may lead to situations, as found with a number of sludge incinerators, in which municipalities fail to keep systems running because they could not plan for the true O&M costs under EPA's evaluation framework.

Ocean Standards

In response to the "Ocean Dumping Law," PL 92-532, final regulations and criteria for ocean dumping were promulgated January 11, 1977. Standards were set for ocean dumping permits and criteria that could not possibly be met by the sludges currently being ocean dumped. The law was amended in November 1977 by PL 95-153 and outright banned all ocean dumping of sewage sludges by December 31, 1981. The new law has created a federal policy that eliminates ocean dumping as a disposal option without due consideration of local factors.

The study team believes that the present federal policy on ocean dumping of municipal wastewater sludges has two main deficiences.

1) The federal policy appears to have much more of a legal basis for its existence than a scientific one. The scientific features of the "ocean ban" policy are particularly vague and are not set within a broad qualitative or quantitative framework. The impression is left that were it not for the excesses of dumping in the New York bight area, little other scientific basis for the ban would exist. An additional need for a scientific framework exists if this policy is to be sensitive to information on negative environmental effects as well as to positive ones.

2) The EPA's decision to ban ocean disposal of sludge has been made without considering the environmental and economic aspects of alternative disposal modes. Risk-benefit analysis comparing all disposal options is needed, not only as a basis for justifying the present ban, but also for anticipating the environmental impacts of all options.

Additional Recommendations

Additional recommendations for improvement in sludge management planning at the national level appear below.

- The study team has concluded that it is possible to determine in an inexpensive manner the amount or percentage of metals contributed to the sewerage system by industrial and commercial dischargers. The method consists of sampling and analyzing the metal content of "raw" influent wastewater during holidays when the predominant commercial and industrial activities cease and then comparing these data (in concentration and loading terms) to data obtained during typical work week periods. By performing these studies under dry weather flow conditions and carefully choosing the appropriate holidays (such as Labor Day and Christmas), establishing the extent of point source contribution of metals should be possible. The study team recommends that EPA encourage municipalities to adopt such a method as part of their industrial wastewater survey procedures.
- EPA should obtain and quickly distribute information on the operational aspects of newly introduced technologies. This need is particularly acute in the case of the autogenous incineration option. At the moment, no organized body of data is available to those municipalities desiring to have such data to use as part of a decision process.
- The study team recommends that EPA develop information on the leachability of metals and other toxicants from ash (which results when sludges are incinerated). This information is needed to allow municipalities to environmentally assess site-specific hazards of ash disposal.
- EPA should update air pollutant emission factors for sludge incinerators, especially with regard to heavy metals and chlorinated hydrocarbons. This updating should be done in conjunction with alternative control methods such as afterburners and venturi scrubbers.

- EPA should formulate an ocean disposal policy that considers the benefits of sludge recycle and reuse. Since oceans are nutrient deficient, the contributions of phosphorus and nitrogen in particular would be beneficial to the marine life.

- The human health effects caused by industrial exposure to cadmium serve as the bases of concern for potential toxic effects to persons consuming food grown on cadmium contaminated, sludge amended soils. Human health effects resulting from ingestion of such food crops, however, appear largely undocumented. Nevertheless, EPA has proposed cadmium limits that strongly govern sludge loading rates and, hense, the overall economic status of a major disposal and reuse mode.

  Some issues that are raised by EPA's regulatory posture are as follows.

  - Of the crops that concentrate cadmium, such as lettuse and swiss chard, How much lettuce must a person ingest before cadmium toxicity is evident or
  - If animals are fed crops grown on cadmium contaminated soils what levels of cadmium occur in the edible organ meat such as liver? How much liver must then be consumed to result in cadmium toxicity?

  The answers to the complex questions have now become critical parts of the justification of EPA's proposed cadmium-sludge limits.

  While the importance of these limits recognized this problem seems to pose little immediate threat to human health. As a result the following approach is suggested. The uses of sludge should be restricted to nonhuman food chain crops and limits should be removed from uses of sludges for growth of animal feed crops until after a long trial period. Trial periods of up to 10 years would probabley be necessary to show the needed effects. By adopting this approach, EPA would remove many of the regulatory impediments to landspreading without increasing risk to humans.

5.5 Recommendations for Improvements in Local Sludge Management Planning

Recommendations for improvements in primary sludge management planning at the local, state and regional level appear below.

MDC

- The MDC industrial waste management program for surveying and monitoring the industrial and commercial contributions of metals to the sewerage system should be modified and accelerated. To obtain accurate information, one modification is necessary: sampling and analysis should be under the control of the MDC.
- If the composting option is adopted, the MDC should consider recommending to its member communities that each be required to accept and dispose of on parkland an amount of composted sludge equivalent to its population's contribution.
- The MDC should develop a research and development capability with expertise in the marine environment. This recommendation is needed because (1) the MDC currently has no scientific or technical capability in the marine area, and (2) its major treatment facilities currently discharge into the ocean.
- The MDC should consider funding studies that document marine impacts of ocean disposal to build a case for or against such disposal in the event that EPA changes its ocean disposal policy. Both the fate and effect of ocean discharged sludge should be investigated.

State

- The MDC should begin to work, with respect to planning and decision making on matters of sludge and related issues, in closer contact with other departments within EOEA. The institutional arrangement of the MDC within EOEA is particularly suited for a broader MDC participation, although what is needed is "action."

- State guidance material that goes beyond the minimal guidance provided by the DEQE letter (Appendix 5A) is needed and specific technical and procedural requirements that would constitute reasonable and technically defensible standards for land application and landfill should be developed. The recommendations of the Commission on Organic Waste Recycling may provide the basis for such standards.
- The DFA should adopt an active role in directing federal wastewater funds directed into agricultural uses. This action would contribute to its stated goal of preserving agriculture in Massachusetts.

Region I
EPA

- Region I should, as part of its EIS for primary sludge, include the composting option.
- Region I should closely examine those aspects of MDC's functions that may conflict with EPA's grant eligibility requirements for construction grants. In particular, conflicts arise because the MDC is unable to raise funds without undue legislative impedence. Such funds are needed to carry out its own research and demonstration programs, as well as to implement programs such as purchase of lands outside of the sewerage district (for example, landfill and land application sites). Without the ability to independently raise funds, the MDC cannot realistically evaluate certain options.
- Region I, in cooperation with EPA's Naragansett Laboratory, should increase its research activities (currently near zero) in the marine environment. At a minimum, these activities should include an effort to coordinate all sludge- and sediment disposal-related studies. Since the present impacts of marine sludge discharges are largely undocumented, a scientific information base is needed, particularly in the event that the ocean disposal policy is changed.

- Region I (as well as all Regional EPA offices) should play a greater "technology transfer" role and provide its constituent municipalities with current and relevant information on topics of wastewater and sludge treatment disposal. This "clearinghouse" function is recommended in the Clean Water Act of 1977, Section 7.

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APPENDIX 5A

LETTER FROM D. STANDLY, COMMISSIONER, DEQE

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
Department of Environmental Quality Engineering
100 Cambridge Street, Boston 02202

DAVID STANDLEY
COMMISSIONER

August 19, 1977

Mailed 8/25/77

RE: Sludge Disposal

Greeley and Hansen Engineers
c/o Mr. R. Srinivasaraghavan (Nivas), PhD
222 South Riverside Plaza
Chicago, Illinois 60606

Dear Sir:

In reply to the questions raised in your letter of 8 June 1977, in the same numerical order, please be advised as follows:

1. At the present time, application of liquid sludge on agricultural land surfically is not permitted in Massachusetts. On an individual basis we would consider application of liquid sludge (6% + solids) in land by injection, subject to nitrogen and heavy metal limitations.
2. Application of dewatered sludge on agricultural land is not generally permitted due to hazards of the spread of disease similar to (1) above. Application by incorporation would be considered subject to method, and to nitrogen and heavy metal limits, providing the sludge was plowed or harrowed into the land the same day as applied.
3. Sludge application in "other" types of land would be considered on a case basis. Massachusetts is both heavily populated and heavily wooded. Most open land is cleared by man and has to be kept open or it will revert to forest.
4. After composting or heat treatment, application on land would be based on limitations of nitrogen and heavy metal content.
5. Landfill is an approved method for sludge disposal when the sludge is dewatered to 18-20% solids and mixed 1:3 with refuse by volume.

Please be advised that Massachusetts has a "Commission" studying the constructive use of sludge and other organic wastes and legislation to establish a "Compost Authority" is pending in the General Court.

Very truly yours,

David Standley

David Standley
Commissioner

DS/kd/PTA

APPENDIX 5B

BENEFITS OF LANDSPREADING

APPENDIX 5B

BENEFITS OF LANDSPREADING

The two main sludge disposal options in the land use category are (1) composting followed by disposal of the compost on parkland presently owned by the MDC and for which the concern for toxic substances in the sludge is minimal and (2) the use of digested or composted sludge on farmlands. The latter could contribute to the general well-being of the Commonwealth because of the number of jobs created and the stimulus that this disposal method would create for the Commonwealth's agricultural business, whether the sludge was used on MDC or private land. The presence of toxicants in sludge raises significant concerns for the second option at this time. Together, these two options provide a flexibility not seen with other types of options. With composting, the MDC could implement an environmentally acceptable disposal option without foreclosing other alternatives (this would not be the case with incineration). By first adopting the composting option, sufficient time could be gained (by disposing of compost on parklands) to reduce further the levels of metals and salt. Additionally, the MDC would acquire experience in landspreading and the legislative authority to acquire land. It is acknowledged that, at the present time, without the concentrated effort of the state government, the MDC would not be able to implement the land application option because of the difficulties involved in raising money to purchase the necessary 5,000 acres of land.

Since the benefits of composting are more straightforward, the following discussion will be limited to the potential benefits of disposing of sludge on farm land.

Benefits of Landspreading of Sludge

The uncertainties affecting the application of sludges to farmland have been discussed previously. As in the case of incineration, uncertainties can be viewed simply as costs that may have to be incurred at some time in the future (for example, in the event of system failure). What then are the corresponding benefits that can be obtained using this option? The answer to this question can be found within the unique institutional arrangement of the Executive Office of Environmental Affairs.

Within the Executive Office are two commissioners with two different tasks. One, the MDC Commissioner, is charged with developing an acceptable sludge management plan and the other, the Commissioner of Agriculture, is concerned with ways to reverse the precipitous decline of agriculture in the Commonwealth. This decline is marked by the annual loss of 20,000 acres of agricultural lands. Since 1964, more than 300,000 cultivated acres have been abandoned or developed.

While the Department of Agriculture has interests that are clearly statewide in focus, the MDC is a regional agency, defined by its service area. However, since this service area includes approximately 40% of the total population of the Commonwealth, it could assume much broader responsibilities or goals. Thus, on the basis of the above viewpoint, it is possible to argue that the decision process on issues such as sludge management planning should be broadened to take into account the Department of Agriculture and other Statewide interests.

The manner in which the Commonwealth might benefit by a decision to funnel federal water pollution control dollars on the order of 25 million dollars (capital costs) for the landspreading of primary sludge is discussed below.

Benefit 1

A benefit can be assumed from the increased farmland, which would be equivalent to approximately 5,000 acres needed for spreading primary sludge. (An additional 15,000 acres would be needed for secondary sludge (1995 designation) with a correspondingly greater benefit).

Benefit 2

Besides the direct benefit of farming itself, landspreading sludges could serve as a nucleus of a several million dollar annual addition to the state's agribusiness. Although the specific details of the potential stimulus are beyond the resources of this study, the type of possibilities are shown in Figure 1. The number of local jobs created by the landspreading option for each

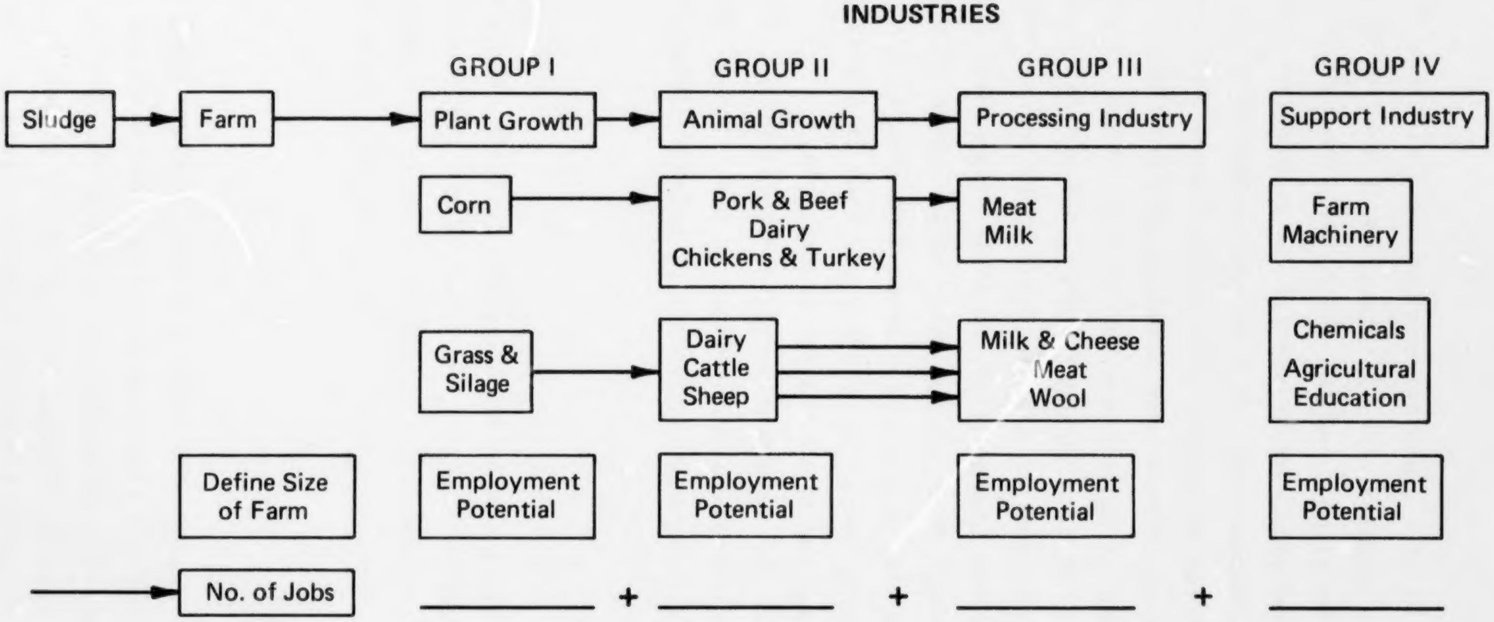
INDUSTRIES
GROUP I
GROUP II
GROUP III
GROUP IV
Sludge
Farm
Plant Growth
Animal Growth
Processing Industry
Support Industry
Corn
Pork & Beef
Dairy
Chickens & Turkey
Meat
Milk
Farm Machinery
Grass & Silage
Dairy
Cattle
Sheep
Milk & Cheese
Meat
Wool
Chemicals
Agricultural Education
Define Size of Farm
Employment Potential
Employment Potential
Employment Potential
Employment Potential
No. of Jobs
+
+
+

Figure 1 Stimulating Effects of Landspreading of Sludge on Agricultural Industries in Massachusetts.

ton of sludge disposed will probably be greater than any other treatment and disposal option. More significantly, those jobs would be in the agricultural sector.

Benefit 3

A feedback incentive system would be created (which has happened with Chicago's MSD) whereby the MSD would have to operate their sewerage system more expertly to improve and ensure the quality of domestic sludge. This system would develop when industrial pretreatment regulations are enforced, since the quality of the sludge would be reflected directly in the quantity and quality of the crop produced.

The first two benefits are related to the broader interests of the Commonwealth. The third applies to the narrower interests of the MDC. The direct and indirect benefits will probably be smaller if the incineration is selected.

6. PUBLIC COMMENT AND RESPONSES

This section presents comments specifically addressed to this report on sludge management planning in the Boston metropolitan area. The draft final report was distributed to concerned organizations and made available to individuals for comment before scheduled public meeting. Two days of public meetings on the Federal Boston Wastewater Management Case Study were held in Boston on September 26 and 27, 1978 at EPA Region I.

Organizations and individuals submitted both oral and written comments. Responses to the written comments are presented in this section. Each set of comments is presented in full, followed by responses specific to each separate comment.

Comments were received from the following organizations and individuals and are reproduced verbatim, followed by the appropriate response.

6.1 Michael B. Cook, U.S. EPA

6.2 Daniel O'Brien, U.S. EPA Region I

6.3 Rebecca Hanmer, U.S. EPA Region I

6.4 Massachusetts Division of Water Pollution Control

6.5 Fifi Nessen, Executive Office of Environmental Affairs

6.6 John Murphy, Boston Harbor Pollution Committee

6.7 Sludge Subcommittee, Boston Harbor Citizens Advisory Committee

6.8 Arthur Barnes, Norumbega Association

6.9 Lydia Goodhue

6.1 Michael Cook, Acting Director, Facility Requirements Division (WH547), U.S. EPA

Comment

On page 49 of the Introduction, the report recommends delay and staging for sludge disposal due to changing technology and regulation. The report cites uncertain incinerator technology and the possibility that ocean discharge may be allowed in the future. EPA recognizes the potential benefits of staging wastewater facilities in order to develop overall cost-effective programs. The Agency's new Cost-Effectiveness Analysis Guidelines require such staging within areas of rapid population growth. Interim sludge disposal programs may result in significant benefits from increased flexibility and technological development. However, delay cannot be accepted based on speculation concerning future legislation.

On page 55 of the Introduction it is recommended that, for disposal options such as co-combustion, the regulations be changed to allow a municipality to contribute construction grant funds for a portion of a private facility in return for partial ownership. Construction grants must go to public bodies created under state law, with legal authority for the disposal of wastes. Such a public institution may use grant funds in conjunction with private capital for the construction of a multi-purpose project. However, the purpose of the construction grants program is to expand the nation's capacity to manage wastewater, and grant funds are not available to purchase ownership in a facility that already exists.

Page 57 of the Introduction implies that costs are the only consideration of cost-effectiveness analysis and recommends consideration of uncertainty. We would stress that while costs are the major consideration, several other factors must be considered in a cost-effectiveness analysis. As already discussed for a similar recommendation in the USR&E report, our guidance states that significant costs, effects, and benefits should be displayed for each alternative and careful judgment should be exercised when evaluating these alternatives.

On page 58, the report contends that O&M costs are understated with respect to capital and recommends consideration of inflation in cost-effectiveness analyses. This issue is also addressed in the discussion of the Urban Systems Research and Engineering Report.

On page 59, the report states that the decision by EPA to ban ocean disposal of sludge has been made without considering the environmental and economic aspects of alternative disposal modes. We would note an earlier statement on the same page of the report that P.L. 95-153 contains an outright ban on all ocean dumping of sewage sludges by December 31, 1981.

Responses

P. 49 - The section on time-staging and decision analysis was an attempt to analyze the benefits of delay, and it is our hope that the results of such analyses may lead to changes in the law and/or regulations. As was pointed out, we do not recommend this option to the Boston area, since it is illegal. However, since the benefits are large, we recommend that national decision-makers consider the issue of when may be the right time to make decisions. In various parts of the wastewater program (e.g., 208 and AWT), major commitments have been made to planning of implementation before the technology was available or before the problems were well defined. We simply suggest that it may be more rational at times to look at the evidence before jumping headlong into solutions.

P. 55 - We agree that the law requires public facilities. We believe that this is an undesirable constraint, and we are not suggesting purchase of capacity in existing facilities, but rather in new ones.

P. 57 - We agree with the comments, but have found in practice that cost is the overriding concern.

P. 58 - See the responses by USR&E since this topic is discussed in considerably more depth in the "Institutional Study."

P. 59 - We agree that the law requires such a ban on ocean dumping (though not, it appears, on ocean discharge); we believe that the law should be questioned.

6.2 Daniel O'Brien, Municipal Facilities Branch, U.S. EPA Region I

Comments

Executive Summary, Page:
(Arabic numerals have been used)

29 Pilot testing of dewatering alternatives would be conducted prior to design.

30 The EIS recommended the use of filter presses (pending additional studies) to ensure a higher percent solids.

31 There is a strong possibility that the MDC will request to re-examine the feasibility of pyrolysis, prior to design, due to the recent advances in this field. They may also investigate what considerations are involved in the retrofitting of a multiple-hearth incinerator to a pyrolysis mode.

32 The coincineration option was lower in annual costs if grants were not considered, but was higher after grants were applied. The co-incineration option was less expensive to the City than mono-treatment so they did realize a "cost savings," but at the expense of the MDC. This point was the main flaw in the co-incineration option. The City would in essence be using MDC's eligibility under 92-500 to reduce their own costs. This information is all summarized on Tables 1 and 3 of the Stone and Webster Report.

33 The Air Quality section of the draft EIS has been revised substantially.

34 We do not see the relationship to the Boston Case Study of the fact that landspreading is successful in many small, midwestern cities.

35 In the "upgrading" EIS, EPA recommended composting of about 25% of the secondary sludge and felt that there was a reasonable market for this amount. We question the feasibility of suggesting that both primary and secondary sludge be composted without a more detailed marketing study being done. In addition, given the timing on implementation of a pretreatment program and the higher nutrient value of secondary sludge, we feel that the EIS recommendation is more realistic.

The summary should include the land area requirements for a composting operation on Deer Island.

The suggestion for distribution of compost to member communities in proportion to their flow contribution is appealing, but merely amounts to "passing the buck" unless a market can be established. In addition, given the development in this area, compost markets are probably inversely proportional to flow contribution.

36 The issue of ocean dumping/discharge is a national one that the EIS did not attempt to address in much detail, however, we feel that the intent of Congress on this subject is fairly clear given the legislation enacted over the last five years or so.

46 The discussion on eligibility here is a bit misleading. All MDC-related facilities are already totally eligible, so that increased eligibility would not directly affect MDC costs. However, it could be assumed that if the City had less expenses it would reduce the "tipping fees" for its customers such as the MDC.

48 The "upgrading" EIS did in essence develop a hybrid option that included incineration, composting, and landfilling.

49 The feasibility of implementing an interim short-term solution has a few drawbacks as follows: unavailability of a realistic short-term solution, uncertainties on future federal funding, more stringent regulations, and more evidence of adverse impacts of certain land-related options.

52 The new MDC ordinance has been promulgated. We believe that its delay was caused by a lack of federal pretreatment standards, not a lack of political acceptance.

55 Performing an EIS on a recommended action does not constitute rejection of that action.

It was felt that by the time secondary treatment came on line, an effective pretreatment program would be in place, not that secondary treatment would reduce the metals content of the sludge.

56 The EIS was not the sole cause for delay. The promulgation of the new Clean Air and Resource Recovery Acts added to the delay and were hurdles that the MDC would have had to clear anyways, possibly after they had started design.

59 The contractor's points on inflation are well-taken.

63 The MDC recently initiated a comprehensive 2-1/2-year study on, among other subjects, pretreatment.

64 In a letter dated January 7, 1975, from former EPA DRA Johnson to former MDC Commissioner Sears, it was recommended that the option of co-incineration with the City of Boston be explored. This suggestion was made before it was even decided to do an EIS and over a year before the Draft EIS was eventually published. The contractor's description of this sequence of events is wrong.

Responses

29 We agree.

30 We agree.

31 We agree that this is desirable, based on current evidence.

32 The cost to the nation is lower--the fact that inequities occurred when grants were applied was our point.

33 No response is possible since we have not yet seen the revised draft EIS.

34 We have amended the text to include Chicago, a large metropolitan area as an example of a city that is "successfully" landspreading.

35 We did not suggest that both primary and secondary sludge be composted; we only addressed primary sludge. While it may be cost-effective to compost secondary sludge, a major issue that needs resolving is the location of the additional acreage since it is not possible to locate it at Deer Island.

The issue of "markets" is of secondary importance since we showed that in the "worst case" situation, where half the compost could not be given away and therefore would require landfilling, the composting option was still cost competitive with incineration, etc.

EPA's comment about pretreatment is for the most part irrelevant since the compost use that we considered did not involve food chain crops but considered uses such as landspreading and maintenance of parks. Our suggestion that member communities accept compost in proportion to their respective contributions is not, in our opinion, "buck passing" since any such suggestion would need considerable analysis before such a conclusion was possible. For example, a communities' park land acreage would need to be evaluated. No doubt some communities such as Lexington, Newton, and Wayland have considerably more parkland than Boston or Cambridge, but depending on the loading rates per acre, even urban areas may be able to accept significant quantities. We think the idea warrants more consideration.

.36 We agree that the intent of Congress was clear concerning the laws governing ocean dumping/disposal of sludge; we recommend that Congress reconsider the ban on ocean dumping and base its decision on available technical information such as environmental impacts.

.46 Our discussion states that the second case assumes that the complete facility is eligible; it could, for example, be an MDC facility taking solid waste as a supplementary fuel for sludge handling.

48 We agree and are pleased with its consideration.

49 There is currently, however, an interim solution being used: ocean discharge. It, too, has uncertainties on future use, more stringent regulations, and some questions about adverse impacts.

52 Our point was that, without federal standards, it was politically impossible to implement pretreatment regulations because of the potential economic implications.

55 We acknowledge that EPA did not formally reject the MDC sludge management plan. More accurately, EPA reviewed MDC's plan and then proceeded to prepare its own version of a sluge management plan.

We feel that EPA's response is not consistent with the following quotation taken from the Draft EIS. "Since secondary sludges typically contain greater concentrations of nutrients and heavy metals are removed in the primary sludge, the future land application of secondary sludges would probably be more feasible than it is now."

56 This appears to be true; also, there still are hurdles; and will continue to contribute to the delay because of the moving target of sludge regulations.

63 Thank you for the information.

64 Thank you for the information. Our text has been changed accordingly.

6.3 Rebecca Hanmer, Deputy Regional Administrator, U.S. EPA Region I

Comment

A key issue raised in the Sludge Case Study Report was that ocean disposal of sludge in the Boston area is a potentially cost-effective solution that should be given more consideration. Under federal law, ocean dumping of sludge is prohibited after 1981. The case study writers apparently feel that the law should allow more flexibility on a case-by-case basis. This national issue is one that has been decided by the Congress, speaking for the American people. It is clear that the national consensus is that the oceans should not be used as a dumping ground, no matter how convenient. EPA must enforce the laws it is given responsibility for administering, and the agency does not intend to make an exception with regard to the legislative prohibition on continued dumping of sludge.

Response

We understand that it is the responsibility of the EPA to uphold the law. Our comments on ocean disposal of sludge were intended for Congress and OMB and were critical of the lack of technical base to support such legislation.

6.4 Massachusetts Division of Water Pollution Control

Comment

This report is critical of the choice of incineration for sludge treatment rather than a less technologically intensive alternative such as composting, landfilling, and ocean discharge. In light of the current federal laws, there is no need to discuss why ocean discharge of sludge was not considered. However, the recently completed EIS contains recommendations which do impact on this report. The EIS recommends that the new Nut Island and Deer Island facilities both be constructed on Deer Island. The recommended sludge management plant calls for incineration of primary sludge and Deer Island secondary sludge, composting a portion of Nut Island, secondary sludge on Squantum Point, and landfilling the remaining secondary sludge as an unspecified 84-acre site. The ERT sludge report prefers composting over incineration but found it to be cost effective only if the composting occurs at Deer Island. Since the facilities are recommended to be combined at Deer Island, there will not be sufficient land available to compost. Given the recommendations of the EIS, it appears appropriate to continue with plans for primary sludge incineration.

Response

This report did not "prefer" the noncombustion alternatives. While the report was indeed critical of the choice of incineration, it was also critical of the EPA's and MDC's failure to consider composting. We did not cost the composting option at sites other than Deer Island; therefore, it cannot be said whether composting is or is not cost effective with incineration if it is performed at some other site.

6.5 Fifi Nessen (EOEA) Massachusetts Executive Office of Environmental Affairs

Comments

1) The EOEA has found the Boston Case Study reports to be very useful. They have provided all of us, government agencies and citizens alike, with a perspective on the wastewater construction grants program underway for Boston Harbor and have served to re-emphasize the need to keep water quality objectives as a prime goal of the program.

2) I am limiting my comments to the sludge management report since my responsibility to the Secretary of Environmental Affairs lies in sludge management. This study, as you know, focuses on the primary sludge management issue for Boston Harbor. One of its findings is that the technical uncertainties and risks associated with projected incinerator performance, pyrolysis, and land application, warrant delay of a commitment to a large capital solution. The report also points out that the sludge management program has been underway for seven years and is not yet finalized. During this time, and for several years to come, sludge continues to be discharged into Boston Harbor, contributing to its pollution. In retrospect, we can see that the rapidly changing technology, economy, and energy situation have mitigated against a simple, easily implemented

solution. There is a lesson to be learned from our experience: a more comprehensive planning approach, including thorough evaluation of alternative and innovative technologies earlier in the construction grants process might have avoided some of the delays incurred in this project. More importantly, there is a point at which interim remedies, like composting, which are not as costly as a large capital investment, are needed to alleviate pollution and to provide meaningful information that would help evaluate alternatives in a period of rapidly developing technology. Although we would not view ocean disposal as a viable alternative, even on an interim basis, we do believe that after seven years, some action must be initiated to diminish or eliminate sludge discharge into the harbor, while analysis continues in an effort to find a long-term solution that is environmentally safe and cost effective. This analysis process would be facilitated by the availability of data on the performance of existing sludge incinerators, and to this end we support the report's recommendation that EPA provide such a clearinghouse service.

3) Another lesson to be learned from the Boston case study, which was also pointed out in the case study report, is that the federal grant structure works against co-incineration alternatives. Though co-disposal is technically feasible and economically and environmentally comparable to mono-incineration in Boston, it was rejected primarily for the two following reasons: (1) the institutional situation complicated implementation and (2) the grant structure made co-incineration more costly for the MDC because grants would be funded only on a pro-rated basis for costs associated with wastewater treatment. The sludge management report recommends that construction grants programs allow a municipality to contribute capital for a portion of a private facility in return for partial ownership. We would also recommend that the grants structure be changed to permit federal funding of co-disposal in dollars equivalent to the cost of a sludge incinerator rather than on a pro-rated basis.

4) At this point, the primary sludge problems in Boston remain unresolved. The case study makes some valid criticism and some good recommendations. It, too, picks up the thread running through the other case study reports: the construction grants program, though well intentioned, has tended to lose sight of its water quality objectives through its focus on treatment facilities. We would hope that the perspective provided by the sludge management report will result in a revised strategy that will allow interim remedial measures to alleviate sludge pollution in instances such as Boston Harbor, where finalization of a recommended long-term solution takes more than five years.

Responses

2) We agree with the view that after seven years, some action should have been initiated to diminish or eliminate sludge discharges into the harbor. We believe, however, that ocean disposal may be "environmentally safe and cost effective," and that the action that should be undertaken is to take steps to evaluate the environmental and technological risks of all the alternatives.

3) This is a possible option for grant eligibility, and would make co-incineration by the public agency operating the treatment works a viable option.

4) We agree with the suggested "thread" and look forward to further sludge planning and implementation efforts in Boston. However, the major focus of the report is to aid in revising the federally influenced process to reduce delays such as the one mentioned and to indicate the nature of the decision processes that have been created by relatively recent regulatory efforts.

6.6 John Murphy, Boston Harbor Pollution Committee

Comments

This form of disposal of sludge [incineration] should not be permitted since its process could be a source of great danger to the health of the people.

The fly ash that will be produced from the burning and the residue that will result must be carted away for disposal as landfill; these are problems that defy adequate solutions.

The prevailing winds over Boston Harbor are north by north-east and east by southeast, usually damp and heavy, which would cause the smoke from the incinerator to lie low over the inhabited area, thereby being a menace to health, particularly breathing ailments.

Then there is the danger from fly ash. Fly ash is the product that is produced from the smoke in the smoke stacks and that must be removed and disposed as landfill; it is difficult to transport and to handle.

Incineration should not and must not be adopted as a means of disposing of sludge or any other waste from sewage filtration plants in the Boston Harbor Area.

We must not recommend the destruction of sludge until we are certain whether or not it can be successfully used as fertilizer for lawns, gardens, etc.

Response

In our criticism we suggested that the EPA reevaluate the worst case condition used for its plume dispersion modeling. As part of that modeling, EPA should consider available wind pattern information and identify areas subject to high pollutant concentrations. We agree that the beneficial uses of sludges should be examined in more detail, especially in light of the stated goals of the Resource Conservation and Recovery Act of 1976 (P.L. 94-580).

6.7 Sludge Subcommittee, Boston Harbor Citizens Advisory Committee

Comments

As members of the Boston Harbor Citizens Advisory Committee Subcommittee on Sludge, we want to make the following comments on the draft final report on sludge management planning in Boston Harbor.

1) The report is a valuable document. It brings together the findings of previous sludge management studies done for Boston Harbor. It is thorough in its analysis including not only all technical aspects but also relevant social and political elements. The material is well organized and clearly presented. We particularly like the division of recommendations along levels of governmental responsibility.

2) We concur with the report's recommendation to delay commitment to incineration until performance data on new incinerators becomes available and enables a more realistic evaluation of the technology. However, we do want to add that the length of time of delay should be specified. We believe two years should be an adequate delay period to gain more accurate information about incineration costs, air quality impacts, and performance reliability. It is particularly important that the disagreement on autogenous potential of the incinerator be resolved because of its affect on operating costs and energy requirements. Once operating data is available, it should be evaluated and incorporated in a brief study (no longer than six months) to update the MDC's sludge management plans.

3) We concur with the report's recommendation for employment of interim disposal methods during the delay period. We would suggest that consideration be given to installation of dewatering facilities during this period to be used for such disposal methods as composting, landfilling, co-incineration, and/or reclamation. One side benefit of interim disposal solutions would be the development of information on costs, effectiveness of process, and marketability, thus permitting a more thorough evaluation of alternatives.

Response

None necessary.

6.8 Arthur Barnes, President, Norumbega Associates

Comments

I am Arthur Barnes, President of Norumbega Association. I was a member of the CAC of the EMMA study. I have been a long-time small boat recreational fisherman with an awareness and appreciation of the fertility of Boston Harbor as a great flounder resource area as well as a beautiful place to sail.

My testimony is based on an appeal to you to think of sewage as a potential public asset and to think of the unique characteristics of our harbor, the Deer and Nut Islands sewerage systems, and the MDC Sewerage District communities which they are designed to serve.

I will suggest that secondary treatment, with the proposed drying and burning of sludge, NOT be pursued, and that instead there be instituted three interrelated projects:

1) upgraded primary treatment procedures for both effluent and sludge,

2) extension of outfall pipes to a point at least 6 miles off Deer Island, and

3) reconstitution of a dilute slurry from the separately treated effluent and sludge, so that the resulting single "homogenized" discharge can be pumped and dispersed continuously with minimization of the tendency of sludge to build up on the harbor bottom.

In making these proposals, I assume that there will be continued progress on several related projects:

1) separation of storm and sanitary sewers in the MDC Sewerage District,

2) interception and treatment of industrial wastes, heavy metals, nonbiodegradable organics, etc. at their source,

3) minimization of point sources of pollution that affect the harbor,

4) upgrading of primary treatment to increase control and reliability, and

5) upgrading of treatment of sludge to minimize toxic characteristics.

I ask that you join me to get a mind-set that allows us to think of sewage, when properly treated, as a rich resource of organic nutrients and a public asset rather than a nuisance. We have observed many years of successful use of both effluent and sludge as fertilizer and soil conditioners when dispersed on farms, forests, gardens, and lawns.

Response

We believe that a potential benefit to the marine environment would result from the discharge of sludge of specified quality (composition). However, the scientific evidence (even with the discharge of a dilute slurry of sludge), is not sufficient, as yet, to be sure that this is the case. Furthermore we know of no studies presently underway designed to investigate these possibilities.

6.9 Lydia R. Goodhue

Comments

1) I agree that Massachusetts should have a sludge management program. At the moment, the forces that want to use sludge as a resource seem to be at odds with the regulators of solid waste, and I hope that very soon the matter will be solved as to whether sludge is a hazardous waste. (And I hope that the matter will be soon solved as to whether cadmium is an insuperable obstacle to land application, as was implied by a federal solid waste official at a recent Technology Transfer meeting.)

2) Of the nine alternatives posed by your study, I am disappointed that you paid so much attention to two ocean sludge disposal alternatives that are totally unacceptable to me. Surely it is not practical to suppose that all but two elements of the sludge can be removed, thus producing a sludge disposal mass that is positively good for the ocean. And, besides, as with talk of putting effluent into the ocean, I am uneasy about the suggestion (5-29) that the policy to ban ocean disposal has "little scientific reason." I fear that we will all live to see the day when the polluted ocean is our main concern, remembering that engineers of good will and training did, several decades ago, design the polluting systems that we have today that are putting effluent and sludge into the nation's streams, lakes, and harbors.

3) I feel uneasy about incineration because of its air quality problems, not yet solved, apparently. Also, I am a great enthusiast of using the resource value of sludge where possible through composting or land application and am pleased to see the MDC's interest in composting and hope that it will continue and expand. Your report makes a good point that the MDC is uniquely able to use the end product on parklands and harbor islands, and I am intrigued with the suggestion that MSD member communities might be required to accept compost for their parks, etc.

4) One of the values of using sludge is that it replaces a certain amount of petrochemical materials now being used and, therefore, when you pose the question (3-55): is reduction of air pollution through composting worth $6/ton?, be sure to include on the benefit side the fact that each ton of compost material reduces our dependence on petrochemical material.

5) I would like to see serious consideration to co-incineration of solid waste and resulting generation of power and cannot believe that one of the impediments is that there is not enough solid waste, when our society seems in danger of inundation by solid waste.

6) Meanwhile, I suggest that the sludge dumping into the harbor be stopped now, even if it means using drying beds at Deer Island or elsewhere until a better solution is found and using more composting. I do not know if the upcoming Final Sludge EIS for Primary Sludge will include a composting element (BHCAC has requested it, but our knowledge of the contents of that EIS as it is being amended is not good).

Responses

1) EPA has proposed draft regulations for the Classification of Solid Waste Disposal Facilities, which include standards for cadmium application to food chain crops; note that application to nonfood-chain crops, including parkland, highway median strips, and sod, is not constrained by the regulation. Thus, the only use of compost that would be highly restricted would be its use as a home garden soil amendment.

2) ERT's views on ocean disposal/dumping of sludge were concerned principally with environmental impacts of these practices. We stated then and we again state that there is little available information to suggest that sludge similar in composition to that generated at Deer Island would have any significant deleterious impacts on the ocean environment. For example, there should be no dissolved oxygen impacts in a well engineered disposal system. Furthermore, sites could be selected that have characteristics such as low biological productivity. The to "metals" in Boston's sludge would be of less concern, given an effective pretreatment program.

3) No comment necessary.

4) It is important to note that we only gain the benefits if the sludge is used in place of fertilizer that would otherwise be used. These benefits are shown through the reduced cost of farming with sludge application.

5) By maintaining a solid waste to sludge ratio of at least 10 to 1, there does not appear to be sufficient solid waste within an economical haul distance for co-incineration of primary and secondary sludges to be a viable option.

6) No comment necessary.